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Foster Wheeler Enviresponse, Inc., Edison, NJ

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16. ABSTRACT

This report covers the field demonstration activities of the U.S. Environmental Protection Agency's Mobile Incineration System (MIS) from February 1986 to June 1989 at the Denney Farm Site, Missouri. These activities were the culmination of a project sponsored by the Office of Research and Development, Office of Solid Waste and Emergency Response, and Region VII to demonstrate the feasibility of incinerating hazardous wastes on-site in mobile incineration systems. The initial part of this field demonstration was discussed in an earlier project summary and associated report entitled, "Destruction of Dioxin-Contaminated Solids and Liquids by Mobile Incineration", dated June 1987.

The activities discussed in the current report include: modifications made to the MIS to double its capacity and to improve its reliability; the 1987 trial burn for Resource Conservation and Recovery Act (RCRA) and Toxic Substances Contract Act (TSCA) wastes; tests to show the feasibility of processing brominated sludge and cancelled pesticides, including testing for metals emissions; delisting tests for the brominated sludge; site and incinerator closure activities; and the accomplishments, problems encountered, and solutions implemented during the operation of the MIS. In addition, a system availability analysis is presented. The information contained in this report is of benefit to those in the public sector who are considering or are currently applying incineration technology as a remedial alternative.

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February 1986 to June 1989

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This report documents modifications to EPA's Mobile Incineration System (MIS), shakedown and compliance testing of the modified system including a RCRA/TSCA trial burn, operating experiences from 1987 to 1989, and closure activities.

For further information, please contact the Superfund Technology Demonstration Division of the Risk Reduction Engineering Laboratory.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

DISCLAIMER

The information in this document has been funded by the U.S. Environmental Protection Agency under Contract No. 68-03-3255 under the sponsorship of the Office of Research and Development. The document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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The activities discussed in the current report include: modifications made to the MIS to double its capacity and to improve its reliability; the 1987 trial burn for Resource Conservation and Recovery Act (RCRA) and Toxic Substances Control Act (TSCA) wastes; tests to show the feasibility of processing brominated sludge and canceled pesticides, including testing for metals emissions; delisting tests for the brominated sludge; site and incinerator closure activities; and the accomplishments, problems encountered, and solutions implemented during the operation of the MIS. In addition, a system availability analysis is presented. The information contained in this report is of benefit to those in the public sector who are considering or are currently applying incineration technology as a remedial alternative.

This report was submitted in fulfillment of Contract Number 68-03-3255 by Foster Wheeler Enviresponse, Inc. under the sponsorship of the U.S. Environmental Protection Agency. The report covers the period from February, 1986 to June, 1989.

MIS FACTS

On the following eight pages is a summary of facts and figures pertaining to the operation of the EPA Mobile Incineration System. Included in this summary are the operating conditions for the system, its overall dimensions and utility requirements, and the results of its various trial burn tests.

U.S. EPA MOBILE INCINERATION SYSTEM FACTS AND FIGURES

DESCRIPTION

Overall Length: 150 ft
Stack Height: 40 ft
Overall Heat Duty: 13.5 MMBTU/hr
Electrical Requirements: 130 KW

OPERATING SUMMARY

	Kiln	Cyclone	SCC	Quench	Stack
Temperature: (°F)	1450	1450	2200	195	175
Pressure: (in w.c.)	-0.3	-2.5 est.	-3.0	-7.0	-15 at fan
Gas Residence Time (sec)	3.0	1.5 est.	2.0 minimum	NA	NA
Feed Rates:					
Air: (SCFM)	560	NA	1200	NA	500 (leakage)
Oxygen: (SCFM)	118	NA	NA	NA	NA
Fuel Oil: (gph)	41	NA	60	NA	NA
Waste Solids: (lb/hr)	4000	NA	NA	NA	NA
Waste Oil:(lb/hr)	150	NA	NA	NA	NA
Water: (gpm)	1.5	NA	NA	61[1]	NA
Discharges:					
Ash: (lb/hr)	2400[2]	400[2]	NA	50	NA
Scrubber Water (gpm)				2 to 12[3]	
Flue Gas (SCFM)	1150	1150	2400	4300	5800

---

[1] Cooling water injected into Quench area about 10 gpm is evaporated by the SCC flue gas the remainder is recirculated.

[2] For a typical soil. This is variable depending on waste characteristics.

[3] The blowdown was adjusted to maintain 20,000 ppm Total Dissolved Solids at the MX Scrubber. This is variable depending upon the organic halogen and sulfur contents of the waste.

(continued)

U.S. EPA MOBILE INCINERATION SYSTEM FACTS AND FIGURES (continued)

TRIAL BURNS

DESCRIPTION	DRE ACHIEVED (%)	PARTICULATE EMISSIONS (gr/dscf)	HCL REMOVAL (%)
Initial Tests:[1] September, 1982 through January, 1983 (Liquid Wastes Only)			
1. Diesel Fuel/Iron Oxide for particulates	NA	0.011	NA
2. Diesel Fuel/Carbon Tetrachloride/Dichlorobenzene		0.029	99.95
Carbon Tetrachloride	>99.99996		
Dichlorobenzene	>99.99998		
3. PCBs/Trichlorobenzene/Tetrachlorobenzene		0.016	99.98
Trichlorobenzene	>99.9998		
Tetrachlorobenzene	>99.9994		
PCBs as Aroclor 1260	>99.9998		
4. PCBs/Trichlorobenzene/Tetrachlorobenzene		0.019	99.99
Trichlorobenzene	>99.99993		
Tetrachlorobenzene	>99.99985		
PCBs as Aroclor 1260	>99.99991		
Dioxin Trial Burn: (Solids and Liquids) (February and April 1986)			
1. 2,3,7,8-TCDD Run#2	99.99997	0.060	NA
2. 2,3,7,8-TCDD Run#3	99.99998	0.065	NA
3. 2,3,7,8-TCDD Run#4	99.99999	0.065	NA
4. 2,3,7,8-TCDD Run#5	99.99998	0.090	NA
5. 2,3,7,8-TCDD/brominated sludge	NA	NA	99.0

[1] The DRE and particulate data are averaged over three test runs.

(continued)

U.S. EPA MOBILE INCINERATION SYSTEM FACTS AND FIGURES (continued)

TRIAL BURN AND TESTS

DESCRIPTION	DRE ACHIEVED	PARTICULATE EMISSIONS	HCL REMOVAL
RCRA/TSCA Trial Burn:			
July, August 1987			
Run 2 Solids Only		0.065	99.97
PCBs	99.9999996		
Carbon Tetrachloride			
Low Vost	NA		
High Vost	NA		
1,2,4-Trichlorobenzene	99.99991		
Hexachloroethane	99.99984		
Run 3 Solids and Liquids		0.066	99.98
PCBs	99.9999995		
Carbon Tetrachloride			
Low Vost	99.99968		
High Vost	99.99958		
1,2,4-Trichlorobenzene	99.99968		
Hexachloroethane	99.9981		
Run 5 Solids, Liquids and Trash		0.085	99.99
PCBs	99.9999965		
Carbon Tetrachloride			
Low Vost	99.99916		
High Vost	99.99869		
1,2,4-Trichlorobenzene	99.99996		
Hexachloroethane	99.999976		

(continued)

U.S. EPA MOBILE INCINERATION SYSTEM FACTS AND FIGURES (continued)

ROTARY KILN

DIMENSIONS

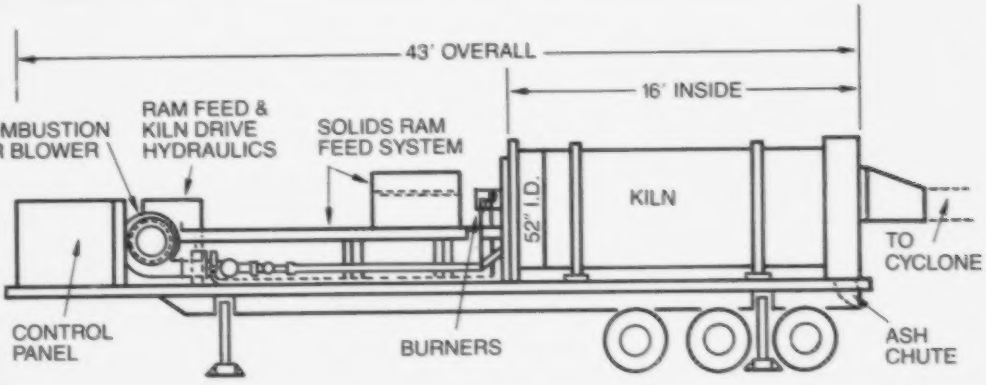
Trailer Length: (ft)	45
Kiln Length: (ft)	16
Kiln I.D. (in)	52
Kiln Volume (ft^3)	236

DESCRIPTION

Kiln: Carbon Steel Shell with Dual Refractory Lining (5-in Combustion Engineering Blue Ram^R plus 2-in CE Lite Weight 58)

Exit Duct: Inconel 601

Burners: 1-Linde A^R Oxygen Burner with Propane Pilot (8 MMBTU) 1-Maxon Fuel Oil Burner with Propanel Pilot (2.9 MMBTU/hr)


43' OVERALL
16' INSIDE
COMBUSTION AIR BLOWER
RAM FEED & KILN DRIVE HYDRAULICS
SOLIDS RAM FEED SYSTEM
52" I.D.
KILN
TO CYCLONE
CONTROL PANEL
BURNERS
ASH CHUTE

KILN FEED RATES

Air: (SCFM)	560	
Oxygen: (SCFM)	118	
Fuel Oil: (gph)	41	
Waste Solids: (lb/hr)	4000	(by permit)
Waste Liquids:(lb/hr)	150	(by permit)
Water:(gpm)	1.5	

OPERATING CONDITIONS

	Normal	Maximum
Temperature (°F)	1450	1900
Pressure(in w.c.)	-0.3	-1.0
Flue Gas Residence Time	3.0	5.0
RPM	1.0	2.0
Solids Residence Time	30	15
Heat Release (MMBTU/hr)	3.0	5.5

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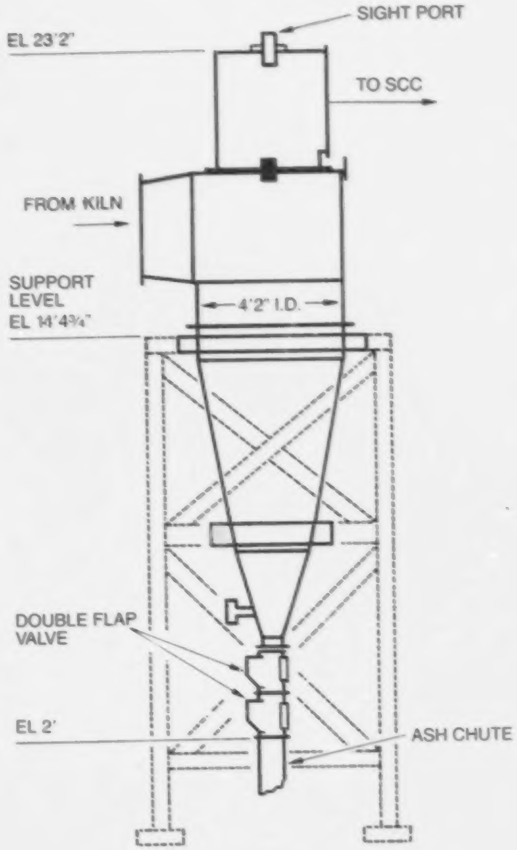
CYCLONE


SIGHT PORT
EL 23'2"
TO SCC
FROM KILN
SUPPORT LEVEL EL 14'4¾"
4'2" I.D.
DOUBLE FLAP VALVE
EL 2'
ASH CHUTE

DIMENSIONS	
Height (ft)	18
O.D. (in)	50
I.D. (in)	38
Volume (ft^3)	

DESCRIPTION	
Cyclone:	Carbon Steel Casing with Dual Refractory Lining (3-in Insulating Resco RS-3 plus 3-in Resco RS-17E. Bottom Casing Inconel 601
Outlet Tube:	Inconel 601

	OPERATING CONDITIONS	
	Normal	Maximum
Temperature (^{o}F)	1450	1900
Pressure(in w.c.)	-2.0 est.	-6.0
Flue Gas Residence Time (sec) (includes ducts between kiln and SCC)	1.5	2.4
Solids Residence Time (sec)	1.5	2.4
Cut Point (microns)	5.0	

(continued)

U.S. EPA MOBILE INCINERATION SYSTEM FACTS AND FIGURES (continued)

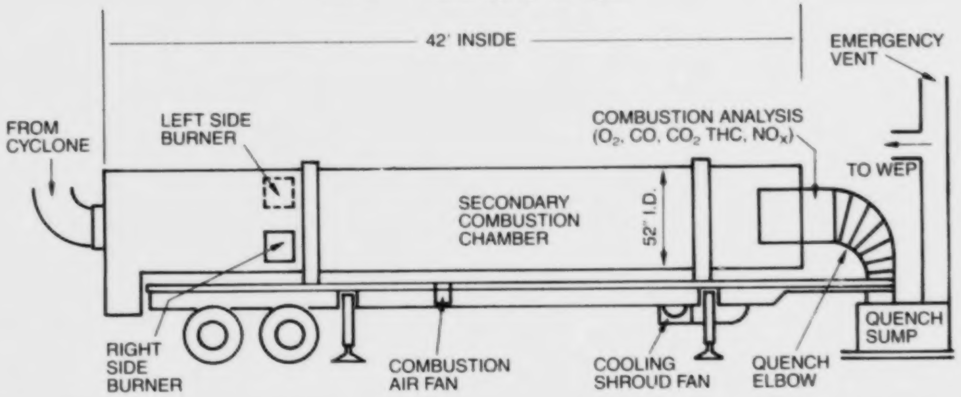
SECONDARY COMBUSTION CHAMBER (SCC) AND QUENCH

DIMENSIONS

Trailer Length: (ft)	45
SCC Length: (ft)	42
SCC I.D. (in)	52
SCC Volume (ft^3)	531

DESCRIPTION

SCC:	Carbon Steel Shell with Forced Draft Cooling Annulus with Refractory Lining 6-in AP Green Kastolite 30
Quench Duct:	Inconel 625 with internal water spray (60 gpm)
Burners:	2-North American Burners with Propane Pilot (8.2 MMBTU/hr Total)


42' INSIDE
EMERGENCY VENT
FROM CYCLONE
LEFT SIDE BURNER
COMBUSTION ANALYSIS (O_2, CO, CO_2 THC, NO_x)
TO WEP
SECONDARY COMBUSTION CHAMBER
52" I.D.
QUENCH SUMP
RIGHT SIDE BURNER
COMBUSTION AIR FAN
COOLING SHROUD FAN
QUENCH ELBOW

SCC FEED RATES

Air: (SCFM)	1200
Fuel Oil: (gph)	41
Waste Liquids:(lb/hr)	none

OPERATING CONDITIONS

	Normal	Maximum
Temperature (^oF)	2100	2400
Pressure(in w.c.)	-3.0	-10.0
Flue Gas Residence Time	2.5	2.0 (Min.)
Heat Release (MMBTU/hr)	5.4	8.2

FLUE GAS COMPOSITION FROM TRIAL BURN:

O_2	CO_2	H_2O	N_2	CO	NO_x	HCl	SO_2
6.0%	10.3%	24.9%	57.7%	19 ppm	96 ppm	1.1%	<300 ppm

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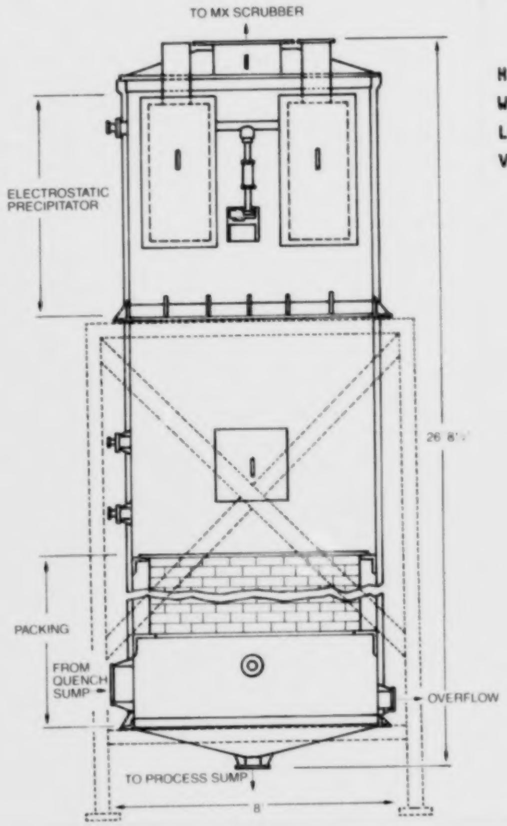
U.S. EPA MOBILE INCINERATION SYSTEM FACTS AND FIGURES (continued)

WET ELECTROSTATIC PRECIPITATOR (WEP)


TO MX SCRUBBER
ELECTROSTATIC PRECIPITATOR
26' 8½"
PACKING
FROM QUENCH SUMP
OVERFLOW
TO PROCESS SUMP
8'

DIMENSIONS	
Height (ft)	40
Width (in)	84
Length (in)	84
Volume (ft^3)	--

DESCRIPTION

WEP:
Housing: Fiberglass-reinforced plastic (FRP) Hetron 97 with 5% Antimony Trioxide.
Collector: Conductive FRP
Rods: 304 Stainless Steel

OPERATING CONDITIONS

	Normal	Maximum
Temperature (°F)	180	200
Pressure(in w.c.)	-7.0 est.	-11.0
DC voltage (KV)	11	13
DC current (ma)	60	60
AC voltage (V)	140	140
AC currrent (a)	25	25
Fog Water (gpm)	--	--
Wash Water (gpm)	--	--

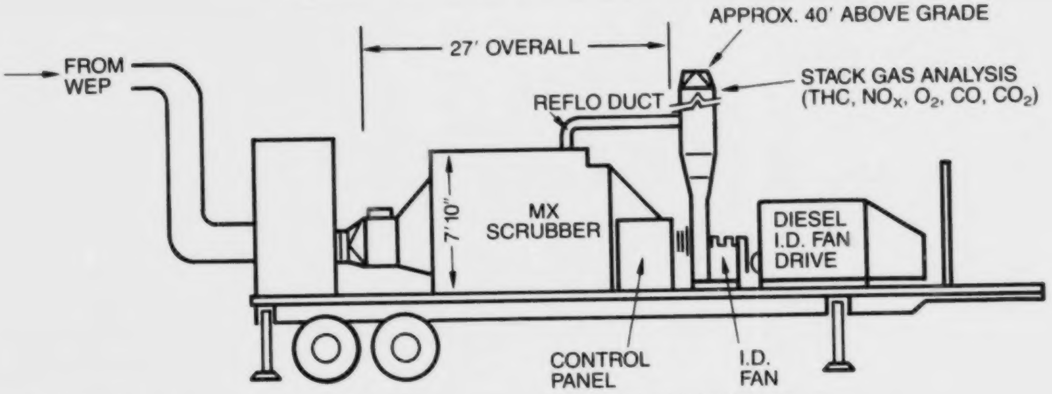
(continued)

U.S. EPA MOBILE INCINERATION SYSTEM FACTS AND FIGURES (continued)

MASS TRANSFER (MX) SCRUBBER AND I.D. FAN

DIMENSIONS	
Trailer Length: (ft)	45
Scrubber Length: (ft)	8
Scrubber Height: (ft)	5
Scrubber Volume (ft^3)	180

DESCRIPTION	
Scrubber:	FRP filled with plastic packing plus a 304 Stainless Steel mist eliminator consisting of a three pass chevron unit and 5-in thick pad
I.D. Fan:	316L Stainless Steel housing with a Inconel 625 shaft and 36-in diameter impeller and 155 HP diesel engine.
Stack:	2-ft x 2-ft 304 Stainless Steel, 40-ft high.


APPROX. 40' ABOVE GRADE
27' OVERALL
FROM WEP
REFLO DUCT
STACK GAS ANALYSIS (THC, NO_X, O_2, CO, CO_2)
7'10"
MX SCRUBBER
DIESEL I.D. FAN DRIVE
CONTROL PANEL
I.D. FAN

MX FEED RATES	
Water: (gpm)	75

OPERATING CONDITIONS	Normal	Maximum
Temperature (^oF)	175	200
Pressure(in w.c.)	-12	-19
HCl Removal Efficiency (%)	>99.9	

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ABBREVIATIONS AND SYMBOLS

acf	Actual cubic feet
ACFM	Actual cubic feet per minute
afpm	Actual feet per minute
MM BTU	Million British Thermal Units
CAA	Clean Air Act
CDD	Chlorinated dibenzo-dioxins
CDF	Chlorinated dibenzo-furans
CEM	Continuous emissions monitor
CHEAF	Cleanable high efficiency air filter
yd^3	Cubic yards
DRE	Destruction and removal efficiency
dscf	Dry standard cubic feet
dvol	Dry volume
EI	Enviresponse, Incorporated
fps	Feet per second
ft^3	Cubic feet
g	Grams
gal	Gallons
gr	Grains
HEPA	High efficiency particulate air filter
HMB	Heat and material balance
HP	Horsepower
hr	Hour
HT	Heat transfer
HWERL (RREL)	Hazardous Waste Engineering Research Laboratory (former name of Risk Reduction Engineering Laboratory)
in	Inches
kg	Kilograms
kJ	Kilojoules
kW	Kilowatts
L	Liters
lb	Pounds
Lpm	Liters per minute
m	Meters
MDNR	Missouri Department of Natural Resources
mg	Milligrams
ml	Milliliters
u	Micron
ug	Micrograms
M5	EPA Method 5
MM5	EPA Modified Method 5
MIS	Mobile Incineration System
MS/MSD	Matrix Spike/Matrix Spike Duplicate
ND	Not detected
NEPA	National Environmental Policy Act
ng	Nanograms
Nm^3	Normal cubic meters

ABBREVIATIONS AND SYMBOLS (continued)

NPDES	National Pollutant Discharge Elimination System
ORD	Office of Research and Development
OSWER	Office of Solid Waste and Emergency Response
PCBs	Polychlorinated biphenyls
PCDD/PCDF	Polychlorinated dibenzo(p)dioxins/furans
PIC	Product of incomplete combustion
POHC	Principal Organic Hazardous Constituent
ppb	Parts per billion
ppm	Parts per million
ppt	Parts per trillion
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
rpm	Revolutions per minute
RCB	Releases Control Branch
RCRA	Resource Conservation and Recovery Act
S/A	Sampling and analysis
SCC	Secondary Combustion Chamber
scfm	Standard cubic feet per minute
scfh	Standard cubic feet per hour
TCDD	Tetrachlorodibenzo-p-dioxin
TDS	Total Dissolved Solids
TSCA	Toxic Substances Control Act
TSS	Total Suspended Solids
t	Metric ton (tonne)
VOST	Volatile Organic Sampling Train
vppm	Parts per million by volume
w.c.	Water column

CONVERSIONS

To Convert From	TO	Multiply By
BTU/lb	J/g	2.326 E + 00
ft^3	m^3	2.832 E - 02
yd^3	m^3	7.646 E - 01
ft	m	3.048 E - 01
^oF	^oC	$t_C = (t_F - 32)/1.8$
gal	m^3	3.785 E - 03
HP	kW	7.46 E - 01
lb	kg	4.535 E - 01
short tons	t	9.072 E - 01
MM BTU/hr	GJ/hr	1.055 E + 00

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IT Corporation was the operating contractor for the MIS from June 1, 1981 through August 31, 1985. On September 1, 1985, Foster Wheeler Enviresponse (FWEI) became the operating contractor. Helge Mortensen was the first FWEI Project Manager of the MIS and managed the implementation of the modifications to the unit from March through May 1987. Robert Sawyer was Project Manager for the trial burn and the operations conducted between June 1987 and June 1989.

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SECTION 1

INTRODUCTION

This report describes modifications made to the EPA Mobile Incineration System (MIS) and discusses the incineration testing and operations conducted from the spring of 1987 until the spring of 1989. The modifications consisted of the major changes implemented in the spring of 1987 to increase the capacity and reliability of the MIS and subsequent changes made to deal with specific feed materials. Testing consisted of shakedown tests prior to the Trial Burn, the 1987 RCRA/TSCA Trial Burn, feasibility testing with vermiculite and brominated sludges, the 1988 delisting tests for the incineration residues from the brominated sludge, and tests on heavy metals emissions.

The report summarizes the various test results, describes the major problems encountered during operation and closure of the MIS, presents the adopted solutions, and discusses the lessons learned. In addition, the effects of various feed materials on the performance of the MIS and the economics of processing these feeds are discussed.

The MIS was originally designed and constructed to demonstrate high-temperature incineration of toxic and hazardous wastes [1]. The system essentially consisted of a refractory-lined rotary kiln, a secondary combustion chamber (SCC), and an air pollution control system. These three components are mounted on three separate heavy-duty semi-trailers. Monitoring equipment is carried by a fourth trailer.

The development of the EPA MIS began in the mid-1970s as a research effort to demonstrate the ability to incinerate oil and hazardous materials on-site. After several years of design and construction, shakedown testing of the unit began in 1981. The MIS was rigorously tested in Edison, New Jersey during 1982 and 1983 with PCB-contaminated liquids and other chlorinated organic fluids [2,3]. After successful completion of these tests, the system was modified to enable incineration of solid wastes. The MIS was transported to the Denney Farm site in McDowell, Missouri, in December 1984 for a trial burn on dioxin-contaminated solids and liquids and for a subsequent field demonstration of the technology. The details of the dioxin Trial Burn and initial field operations at the Denney Farm site have been presented in an earlier EPA report available from the National Technical Information Service [4]. Following the trial burn, a variety of dioxin-contaminated materials were incinerated by the MIS between July 1985 and February 1986. By February 1986 over two million pounds of solids and approximately 180,000 lb of liquids had been incinerated during a total of 170 operating days.

During the field demonstration at the Denney Farm Site, the MIS demonstrated the ability to destroy liquid and solid hazardous wastes. However, the relatively low onstream time of 40% to 60% and low throughput rate of 2000 lb/hr for soils limited its use for the massive task of cleaning up hazardous waste sites. A detailed discussion of the lessons learned and of the problems encountered during the 1985 and 1986 system operation is provided in reference [4].

In February of 1986, MIS operations were suspended for one year pending reauthorization of Superfund. During this shutdown period, a design study was undertaken in order to increase the MIS capacity and on-stream service factor. The two primary reasons for the low on-stream service factor of the MIS were thought to be:

- Excessive particulate carryover from the rotary kiln, which accumulated in the secondary combustion chamber (SCC), requiring a several day cooling down and clean out period.
- Extensive maintenance required on the cleanable high efficiency air filter (CHEAF), a wetted glass fiber particulate filter.

The low soils throughput of the MIS unit was due to a gas residence time limitation in the SCC.

Improvements, identified in the design study, were implemented between March and May of 1987. The trough of the ram feeder was enlarged to allow for feeding a greater volume of material per stroke of the ram. An oxygen burner replaced the conventional air burner in the kiln to reduce the gas flow rate. Thus, the feed capacity could be increased without going below the required 2-second gas residence time for the SCC. A cyclone was installed between the kiln and SCC to remove particulates from the gas stream. A wet electrostatic precipitator (WEP), replacing the CHEAF, was installed to remove particulates downstream of the SCC, and a Monarch^{R} CPI separator was added to remove the suspended particulate matter in the process water stream.

Shakedown of the modified equipment and continuation of incineration operations of materials from the Denney Farm site and other southwest Missouri dioxin sites began in June 1987. The system modifications proved successful. The feed rate of soils increased from 2000 lb/hr to 4000 lb/hr. The cyclone and, to a lesser extent, the oxygen burner caused a great reduction in particulate buildup in the SCC. The WEP was successful in particulate removal and required low maintenance. The shakedown tests revealed that a mist eliminator was required to control particulate emissions with high halogen contents in the feed. This was added in June 1987 prior to the trial burn.

During the following three month period, various system performance tests were conducted, including the RCRA/TSCA Trial Burn. Additionally, over one million pounds of dioxin-contaminated solids and liquids including soil, plastics, trash, grass, Tyvek^R clothing, wood, etc. were incinerated.

The three month operating period during 1987 showed that further modifications were required to increase productivity of the unit. During 1988, modifications were made to the feed system consisting of installing a conveyor belt system from the storage area to the shredder, an adjustable roller to replace the doctor blade that was often the site of blockages when trash was fed to the MIS, and a television camera at the discharge end of the main feed conveyor to provide prompt detection of feed system blockages. The kiln ash gates were modified and repaired. A refractory nozzle was designed to replace the Inconel^R nozzle at the exit of the SCC to reduce the high maintenance requirements of this component. Also, knock-out ports were installed on the ductwork between the kiln and SCC.

Between February 1988 and April 1989, a total of 8,930,000 lb solids and 30,500 lb liquids was incinerated. Thus, over 12,500,000 lb solids and 230,000 lb liquids from eight dioxin-contaminated sites was incinerated between 1985 and 1989. This included material from site and incinerator closure activities which began in January 1989.

After the incinerator ceased operation in April 1989, the equipment was disassembled and transported to the EPA facility in Edison, New Jersey. All equipment was shipped by June 1989. The equipment is currently disassembled while EPA is seeking a technology partner to further develop the MIS under the Federal Transfer Technology Act.

SECTION 2

CONCLUSIONS, ACCOMPLISHMENTS, AND RECOMMENDATIONS

OVERALL ACCOMPLISHMENTS

The Mobile Incineration System (MIS) project has been one of the most successful activities sponsored by the EPA. The MIS has achieved many notable accomplishments, and the engineering solutions to problems encountered during its operation have helped to advance the state-of-the-art of incineration technology. The information gained from the unit has been made available to the private sector. The accomplishments of the MIS are summarized below.

- The MIS has incinerated over 12,500,000 lb solids and 230,000 lb liquids from eight dioxin-contaminated sites.

- The operation of the MIS has shown constant improvement as engineering solutions to the operating problems have been applied. Capacity has been doubled from 2000 lb/hr to 4000 lb/hr, and reliability or on-stream factor has been increased from 40% availability to 80% availability. The private sector has benefitted from the learning experiences.

- Incineration costs were greatly reduced between 1985 and 1989. At closure materials were processed for $1100 per ton compared to a $2800 per ton cost for similar materials at the start of operations in 1985. The cost improvements were caused by the increased capacity and the increased availability of the MIS. However, incineration costs were widely variable. Materials with high heat contents cost more to process because of the lower processing rates achievable with these feeds.

- The MIS has demonstrated the ability to meet stringent up-front delisting requirements for dioxin-contaminated soil and brominated sludges. Dioxin content of the solid residues was not detected at the parts per trillion level, and dioxin content of the liquid residues (process water) was not detected at the parts per quadrillion level.

- The MIS has provided valuable technical information on the capabilities of the incineration process, including Destruction and Removal Efficiencies (DREs), the formation of products of incomplete combustion (PICs), heavy metals emissions, and feed system interactions with various materials. This information has been turned over to the private sector by means of reports and technical papers, which cover trial burns, delisting tests, other technical tests. The daily operation of the MIS including successes, problems encountered, and their solutions have also been documented. More than a dozen reports and technical papers concerning the MIS have been published between 1986 and 1989.

- The MIS was the first system to use a pure oxygen burner to incinerate hazardous wastes.
- The MIS has been fully permitted to burn both solid and liquid dioxin-contaminated wastes.
- The MIS has demonstrated the capability to meet the RCRA requirements for destroying dioxin-contaminated solid and liquid wastes:
    - Destruction and Removal Efficiency of dioxin (DRE) exceeding 99.9999%
    - Acid gas removal exceeding 99%
    - Particulate emissions less than 0.08 gr/dscf
- The MIS has demonstrated the capability of exceeding the 99.9999% DRE requirement for PCBs.
- DREs exceeding 99.99% have been demonstrated for compounds that are difficult to destroy, such as carbon tetrachloride and hexachloroethane.

EFFECT OF MODIFICATIONS TO THE MIS

Modifications implemented in 1987 and 1988 increased the capacity and on-stream factor or availability. To determine on-stream factor, divide the time that materials were actually being processed by the total time elapsed and multiply by 100. The improvements in the operations of the MIS resulting from the modifications are listed below.

- The incorporation of a Linde "A"^{R} oxygen burner system in the rotary kiln was primarily responsible for increasing the MIS capacity for treating soils by more than a factor of two. This system has functioned very well. It has exhibited excellent response, which has reduced the number of feed shutdowns due to low oxygen and high carbon monoxide contents in the stack gas.
- The cyclone has demonstrated excellent performance and it has alleviated the problem of particulate

accumulation in the secondary combustion chamber (SCC). The frequent weekly cleanups of the accumulation and associated downtimes have been almost eliminated. The unit can operate over a period of several months before a cleanup is required.

- The wet electrostatic precipitator (WEP) has demonstrated excellent performance in particulate removal and has solved the extensive maintenance requirements associated with the CHEAF. However, it has had a tendency to occasionally shortout, causing some downtime.

- The Monarch^{R} CPI separator has operated very well and has minimized the suspended particulate matter in the process water system.

- The conveyor belt system, installed in March 1988, to feed material to the shredder has successfully increased production by reducing the frequency of handling the feed materials. This permitted sustained feeding of material at twice the original feed rates.

- An adjustable roller installed in the feed system in January 1988 has reduced the frequency and severity of feed system blockages.

- A television camera placed at the discharge end of the conveyor belt provided prompt detection of feed system jams.

- The repair and redesign of the ash gates at the exit of the kiln has reduced slagging incidents.

Other modifications, noted below, enabled the MIS to successfully incinerate brominated sludge material.

- A mist eliminator installed in the MX scrubber was required to reduce the particulate emissions by a factor of three at high organic halide loadings.

- Knock-out ports installed in the ducts between the rotary kiln and SCC permitted hot clean-outs of ash deposits which accumulated in these areas when the MIS processed brominated sludge.

TESTING AND OPERATIONAL EXPERIENCES ON VARIOUS FEED MATERIALS

The performance capabilities of the MIS on a variety of feed materials have been ascertained. Operational experience during 1987, 1988, and 1989 has shown that feed rates vary widely depending upon the feed characteristics. Relatively dry soil (less than 20% moisture) could be processed at 4000 lb/hr. The heat and moisture contents as well as slagging tendencies of the feed material were the most important variables affecting feed rates. With a 2650 BTU/lb minimum heat content, brominated sludge could be incinerated at only 2000 lb/hr. Pure trash with a heating value up to 18,000 BTU/lb could be processed at rates as low as 200 lb/hr. Feed moisture contents of about 35% produced muddy soil which could be fed at only 2000 lb/hr.

A series of tests including the RCRA/TSCA Trial Burn showed that the unit could process dioxin-contaminated pesticides in an environmentally acceptable manner.

A series of tests were conducted with mixtures of brominated sludge, soil, and sodium sulfate (Na_2SO_4); and with pure brominated sludge. These tests determined that it was best to incinerate pure brominated sludge and they also determined the proper operating conditions for this difficult-to-incinerate material. The critical operating conditions, defined by the tests, were: 1) a low 0.8 rpm kiln rotation speed to provide adequate solids residence time for burn-out, 2) kiln temperature of 1650^oF to 1700^oF to maintain ignition and prevent combustion oscillations, and 3) water injection to control kiln temperature and to maximize throughput.

As a result of slagging in the kiln and troublesome ash deposits in the duct system, tests to ascertain the ash fusion characteristics and chemical analyses of the slag and ash deposits were conducted. The tests showed that slagging was promoted when sodium and potassium content of the ash exceeded 3.5 wt% and that troublesome ash deposits occurred when the ash contained large quantities (50 wt%) of calcium and sulfur.

A metals testing program showed that the metal emissions when processing brominated sludge were below the Tier II emissions screening levels presented in the proposed amendments to the hazardous waste incinerator regulations. Since the Tier II emission levels are health based, this finding showed that health risks from metal emissions were acceptable.

Testing on heavy metals emissions showed how mercury, cadmium, lead, arsenic, hexavalent chromium and total chromium were partitioned between the various residue streams from the MIS. Mercury did not appear in the kiln or cyclone ash in measurable quantities and was probably volatilized. A small amount of mercury was captured by the air pollution control train and it appeared in the stack at concentrations, which were 90 times those in the original feed material. Most of the lead and cadmium were volatilized and, after condensation, were contained in the separator sludge. Furthermore, the concentrations of lead, cadmium, and mercury in the separator sludge and the stack were an order of magnitude higher than in the other solid residue streams. Total chromium concentrations were approximately the same in all solid streams but significant levels of hexavalent chromium were found only in the cyclone ash.

SITE CLOSURE

The closure of the Denney Farm site provides a benchmark example for the clean closures of other incineration sites. Closure at Denney Farm entailed decontamination of Denney Farm soil, decontamination of the hot zone buildings used for storage and handling of hazardous waste, decontamination of hot zone equipment, decontamination of the feed system, and disassembly and transport of the MIS.

The initial closure activities involved sampling and analysis of the site soils and buildings to determine the extent of contamination. The data showed that contamination had spread to areas outside the hot zone. Lessons learned from this spread are as follows.

- The number of waste handling steps should be minimized to prevent spillage of the material and contaminated material should only be handled within diked areas.

- The hot zone areas should be graded so that rainwater can not carry contamination into clean areas.

- Periodic sampling of the site should be conducted to identify contamination and thus permit prompt action to prevent the spread of it.

RECOMMENDATIONS

EPA does not plan to sponsor further field demonstration of the MIS. However, EPA is seeking a technology partner to sponsor the further development of the MIS under the Federal Technology Transfer Act (FTTA). Should the MIS be operated again under the FTTA, the following modifications can be made to reduce the number of operators and utility costs:

1. Automate ash handling.

2. Consolidate all controls into a central control room. This should include the Continuous Emission Monitoring equipment.

3. Install a larger quench sump to insure sufficient water holdup for all the pumps, quench elbow, and WEP.

SECTION 3

MODIFICATIONS TO THE MOBILE INCINERATION SYSTEM

During 1985 and 1986 the operation of the MIS had shown that only 2000 lb/hr of soil with relatively low moisture content or low heating value could be incinerated [4]. Higher moisture content (>30%) or higher heating value feeds (>2200 BTU/lb) further reduced the system capacity. Also, a modest on-stream service factor of 44% to 55% was experienced during this operation. Since the economics of the MIS are directly dependent on the system capacity and on its on-stream factor, a design study was undertaken to determine the capacity-limiting factors and the primary causes of the system unavailability.

SYSTEM PRIOR TO 1987 MODIFICATIONS

The system prior to modifications consisted of: (1) incineration and air pollution control (APC) equipment mounted on three heavy-duty over-the-road semi-trailers, (2) combustion and stack gas monitoring equipment housed within a fourth trailer, and (3) ancillary support equipment. As shown in Figure 1, the incinerator and APC component consisted principally of: (1) a rotary kiln, (2) a secondary combustion chamber (SCC), (3) a wetted-throat quench elbow with sump, (4) a cleanable high efficiency air filter (CHEAF), (5) a mass transfer (MX) scrubber, and (6) an induced-draft (ID) fan. Ancillary support equipment consisted of bulk fuel storage, waste blending and feed equipment for both liquids and solids, scrubber solution feed equipment, ash receiving drums, and auxiliary diesel power generators.

SYSTEM AFTER 1987 MODIFICATIONS

Based upon the findings of the design study, the system was modified to increase capacity and improve system availability. Capacity was increased by redesigning the ram and replacing one of the two conventional burners in the rotary kiln with an oxygen burner. The system availability was addressed by adding a cyclone between the kiln and SCC, replacing the CHEAF with a wet electrostatic precipitator, redesigning the ram feed system, adding a Monarch^{R} CPI separator to the process water system, modifying the quench sump, plus other hardware and instrumentation changes. The system configuration after the modifications is presented in Figure 2. The results of the design study and the system modifications are discussed in greater detail below.

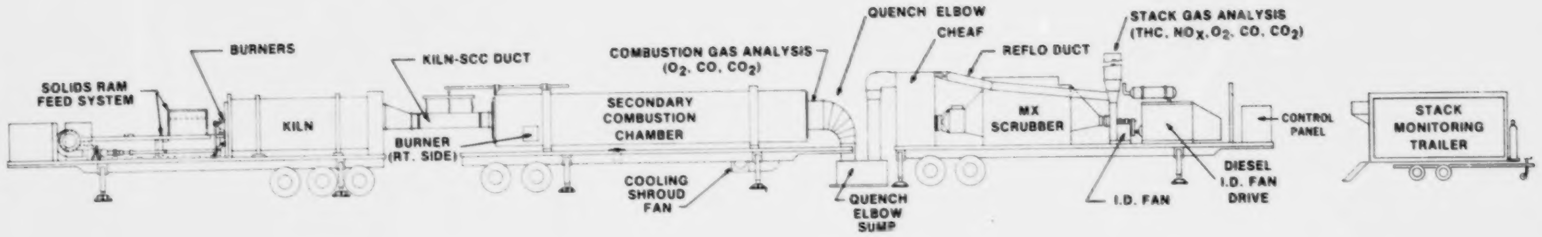

SOLIDS RAM FEED SYSTEM
BURNERS
KILN
KILN-SCC DUCT
BURNER (RT. SIDE)
COMBUSTION GAS ANALYSIS (O_2, CO, CO_2)
SECONDARY COMBUSTION CHAMBER
COOLING SHROUD FAN
QUENCH ELBOW
QUENCH ELBOW SUMP
CHEAF
REFLO DUCT
MX SCRUBBER
STACK GAS ANALYSIS (THC, NO_X, O_2, CO, CO_2)
I.D. FAN
DIESEL I.D. FAN DRIVE
CONTROL PANEL
STACK MONITORING TRAILER

Figure 1. Mobile Incineration System - 1985.

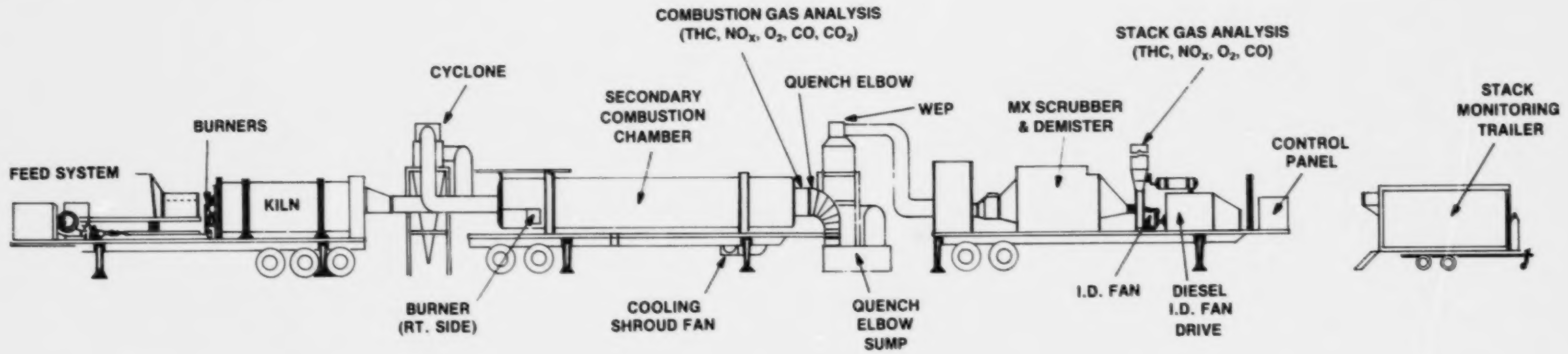

FEED SYSTEM
BURNERS
KILN
CYCLONE
SECONDARY COMBUSTION CHAMBER
COMBUSTION GAS ANALYSIS (THC, NO$_x$, O$_2$, CO, CO$_2$)
QUENCH ELBOW
WEP
MX SCRUBBER & DEMISTER
STACK GAS ANALYSIS (THC, NO$_x$, O$_2$, CO)
CONTROL PANEL
STACK MONITORING TRAILER
BURNER (RT. SIDE)
COOLING SHROUD FAN
QUENCH ELBOW SUMP
I.D. FAN
DIESEL I.D. FAN DRIVE

Figure 2. Mobile Incineration System - 1987.

SYSTEM LIMITATIONS

Capacity

The capacity, i.e., the rate at which the waste material can be handled by the MIS, results from a complex interaction between the physical parameters of the system, the operating conditions necessary to meet the regulatory requirements with respect to stack emissions and delistable ash from the kiln, and the waste characteristics. These major items and their interactions are illustrated in Figure 3.

It was found that the capacity limitation of the MIS resulted primarily from:

- Volume of the ram feed trough, which determined amount of material charged.
- Flue gas volumetric flow rate through the SCC which approached the required minimum two-second gas residence time.

On-Stream Time

During the extended Field Demonstration, the production on-line factor was 55%; i.e., the unit was down 45% of the time. An analysis of the system operations on clay soils during the 1985-86 period revealed that the two primary causes of downtime were:

- Excessive particulate carryover from the kiln which accumulated in the SCC and necessitated system shutdowns for clean-out approximately every week.
- Extensive maintenance required on the CHEAF.

The one element most affecting the on-line service factor was the buildup of solids in the SCC. Approximately 90% of the downtime was attributable to cleaning out the particulate carryover from the rotary kiln to the SCC.

A "cold clean-out" of the SCC (where the system was allowed to completely cool such that personnel could enter the secondary chamber to remove accumulated solids) took anywhere from 60 to 90 hours, with an average feed interruption of approximately 70 hours.

The operations at Denney Farm indicated that the solids buildup in the SCC was a function of the type of soil being incinerated. When processing Erwin Farm soil, a sandy loam river bottom type of soil, up to 25% of the feed was carried over from the kiln to the SCC. This soil was characterized by

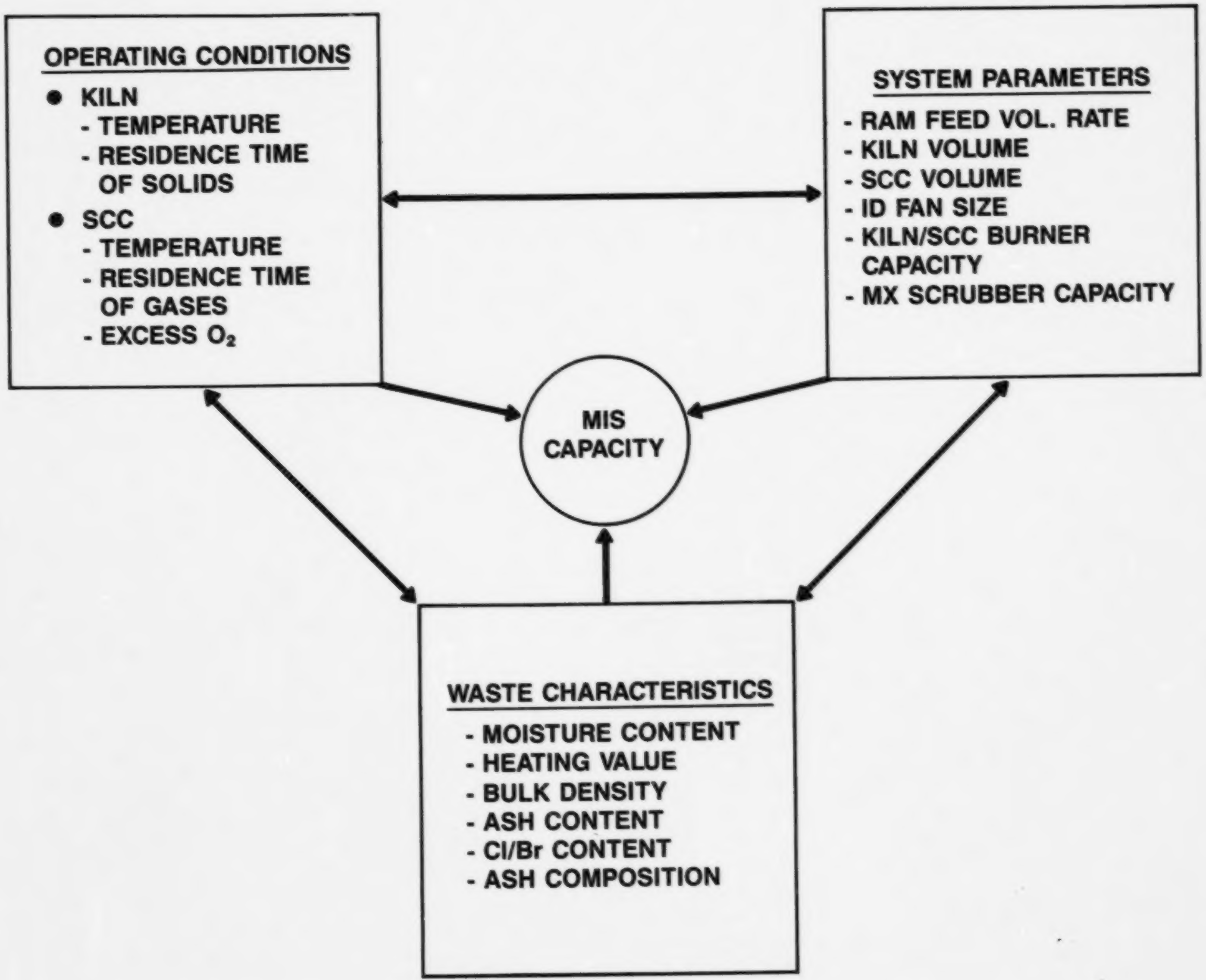

OPERATING CONDITIONS
● KILN
- TEMPERATURE
- RESIDENCE TIME OF SOLIDS
● SCC
- TEMPERATURE
- RESIDENCE TIME OF GASES
- EXCESS O_2
SYSTEM PARAMETERS
- RAM FEED VOL. RATE
- KILN VOLUME
- SCC VOLUME
- ID FAN SIZE
- KILN/SCC BURNER CAPACITY
- MX SCRUBBER CAPACITY
MIS CAPACITY
WASTE CHARACTERISTICS
- MOISTURE CONTENT
- HEATING VALUE
- BULK DENSITY
- ASH CONTENT
- Cl/Br CONTENT
- ASH COMPOSITION

Figure 3. Factors affecting MIS capacity.

a large percentage of fines with 33.4 wt% of the particles less than 100 microns in diameter as shown in the particle size distribution data presented in Table 1. The solids buildup in the SCC necessitated shutdown after processing an average of 127,000 pounds of waste, which required two to three days of operation. By comparison, 480,000 pounds of Denney Farm clay soil were fed during July and August 1985 before operations were stopped for administrative reasons. Operations could have continued to 500,000 pounds of throughput before shutdown for cleanout of the SCC would have been necessary [4]. Denney Farm soil was much coarser than Erwin Farm soil. Only 4.8 wt% of the particles were less than 100 microns in diameter as shown in the particle size distribution data presented in Table 1.

In addition to plugging the SCC, the entrainment of solids also increased maintenance in the process water system downstream of the SCC. In the original system, process water was recycled through the quench system as follows: process water and make-up water was sprayed in the quench elbow to reduce flue gas temperature from 2200°F to 170°F. Then the water was drained to the quench sump and was recycled to the quench elbow through a recirculation pump. The water that was sprayed into the quench elbow scrubbed some of the particulates from the flue gas. These settled in the quench sump and plugged the recirculation pump. This problem was alleviated during the 1984-1985 operating period by installing a hydrocyclone in the quench recycle line.

The primary particulate control device in the MIS air pollution control system was the CHEAF, which utilized a disposable filter media. The filter was placed across the duct perpendicular to the direction of the gas flow. This movement constantly exposed fresh filter surface to the particulate-laden gas stream. The fresh surface collected particulates and the used filter media then was discarded. The CHEAF was designed for treating flue gas with a low concentration of fine particulates. In practice, however, inlet particulate loadings to the CHEAF for the MIS application were very high. These conditions blinded the filter media, leading to excessive pressure drops across the unit. The filter media also developed holes, and bits of filter media got into the process water system. Here they plugged spray nozzles in the MX scrubber and quench elbow. Air leaks between the gas duct and the metal screen-supported filter media were equal to 30% to 50% of the induced draft fan capacity - an effect that, with small changes, significantly altered the vacuum balance of the MIS. This caused shutdowns of the system due to positive pressure in the kiln. Also the price of the consumable filter media was a significant daily operating cost. Due to these problems, replacement of the CHEAF was recommended.

TABLE 1. PARTICLE SIZE DISTRIBUTION OF DENNEY FARM AND ERWIN FARM SOILS AND BROMINATED SLUDGE ASH

Material	Denney Farm Soil (clay)	Erwin Farm Soil (silt)	Brominated Sludge (stabilized)
Particle size (microns)	Cumulative vol% over	Cumulative vol% over	Cumulative vol% over
4760	6.24	0.80	0.00
2380	22.68	9.63	0.00
1190	47.61	24.41	0.00
595	69.73	41.33	0.00
297	85.04	54.53	2.69
149	92.49	63.27	11.05
105	94.65	66.78	16.17
74	96.39	71.18	23.14
44	96.51	71.75	37.52
40.3	96.66	73.00	40.90
32.0	96.83	75.49	48.48
25.4	97.02	78.75	56.26
20.2	97.18	82.17	63.06
16.0	97.33	85.96	69.19
12.7	97.51	88.43	74.88
10.1	97.70	90.40	79.77
8.0	97.92	92.13	83.16
6.4	98.14	93.63	86.32
5.1	98.34	94.83	88.99
4.0	98.52	95.80	91.39
3.2	98.74	96.85	93.89
2.5	98.94	97.60	96.13
2.0	99.12	98.23	97.69
1.6	99.29	98.74	98.76
1.26	99.52	99.27	99.18
1.00	99.73	99.62	99.50
0.79	100.00	100.00	99.64
0.66	--	--	99.73
0.43	--	--	99.90
0.34	--	--	99.96
0.24	--	--	99.98
0.17	--	--	99.99
0.10	--	--	100.00
Mean particle size (microns)	1126	399	30.5

Another significant cause of downtime in the original system was the jamming of the ram feed. This jamming was caused by material which got behind the ram as it moved forward and backward. When the ram moved forward a small quantity of material would go between the ram and the trough. This material would accumulate behind the ram and get packed into a large mass by the backward movement of the ram. When the accumulated mass of material occupied enough volume, the ram could no longer be retracted.

DESIGN CONSIDERATIONS, CONSTRAINTS, AND IMPLEMENTATION

The goal of the modifications was to double the MIS capacity and increase its on-stream service factor to 80%, thereby increasing overall throughput by more than a factor of three. The following factors were considered in order to make the design changes to accomplish these goals: (1) existing space (physical size of the equipment); (2) maintenance requirements; (3) corrosion and erosion; (4) emissions; (5) flue gas system flow characteristics (ID fan head capacity); (6) particle dynamics.

The considerations are discussed below:

Kiln Capabilities

Vulcan Iron Works, Inc., of Wilkes-Barre, Pennsylvania, was retained as a consultant to confirm Enviresponse, Inc.'s analysis of the heat transfer and material flow capabilities of the kiln, to establish the necessary revisions to the operating parameters, such as slope and rotation, and to review mechanical details of the kiln to determine whether the existing drive, thrust bearings, drive chain, etc. would be suitable at higher throughputs.

Vulcan recommended that the solids in the kiln not exceed 12% of its volume. Depending upon the bulk density of the soils, the kiln would be capable of processing 4600 to 7000 lb/hr. At the 4000 lb/hr feed rate, Enviresponse calculated and Vulcan confirmed that the solids will occupy approximately 10% of the kiln volume, have a residence time of 30 min, and exit at a temperature of 1400^{o}F to 1600^{o}F. These conditions were adequate for decontaminating dioxin-contaminated soil.

Based upon Enviresponse's review of MIS operations and Vulcan's review of the kiln, it was concluded that the operating capacity could be increased from 2000 lb/hr to 4000 lb/hr. All upstream and downstream equipment modifications were designed on the basis of this increased capacity.

SCC Residence Time Limitation

When firing the kiln using combustion air, the gas residence time of the SCC limited the solids capacity of the kiln. In order to achieve a Destruction and Removal Efficiency (DRE) of 99.99% of the Principal Organic Hazardous Constituents (POHC) and at least 99.9999% DRE for the dioxins present in the waste, regulations require that the SCC be operated at 2200°F, have an excess oxygen level of more than 3%, and a minimum gas residence time of two seconds. The SCC volume of 531 ft^3 imposes a constraint of 15,930 actual cubic feet per minute (ACFM) through the SCC.

Figure 4 describes a partial heat and material balance for the MIS when using air to sustain combustion and processing 2000 lb/hr of contaminated soil with 20% moisture and 10 MM BTU/hr heat load (total for kiln and SCC). As shown in Figure 4, the 14,060 ACFM gas flow rate through the SCC at 2000 lb/hr of soil is close to the allowable 15,930 ACFM constraint. Hence the SCC volume limits the MIS to a soil loading of about 2300 lb/hr with air. It was decided to investigate oxygen or oxygen-enriched air in the kiln to reduce the flue gas volume in the SCC, thus allowing an increased feed rate to the kiln.

Oxygen Enrichment

The use of oxygen or oxygen-enriched air reduces the volume of both the oxidant and flue gas. As the oxygen replaces part or all of the combustion air, the nitrogen portion (79% of volume of air) is reduced, thereby lowering the volume of the fuel, oxidant, and flue gases per unit of soil processed. This has the direct benefit of increasing the feed rate, reducing the particulate carryover from the kiln, improving the pressure profile throughout the system and reducing fuel consumption. Various levels of O_2 enrichment were considered and it was decided to use 100% oxygen in lieu of air.

Based on a computerized simulation of the kiln conditions in the MIS, the fuel requirement and flue gas volume are plotted in Figure 5 with respect to the system throughput for the original air system and for the oxygen system (modified MIS). Soil with 20% moisture and the same level of oxygen concentration in the flue gas was considered for both cases. Figure 5 clearly shows that the 2 second residence time limit cannot be met at feed rates above 2000 lb/hr using the air system. However, at throughputs approaching 6000 lb/hr, the oxygen burner system amply meets this requirement. Figure 5 also shows that over 50% savings in the combustion fuel requirement can theoretically be achieved by the use of oxygen.

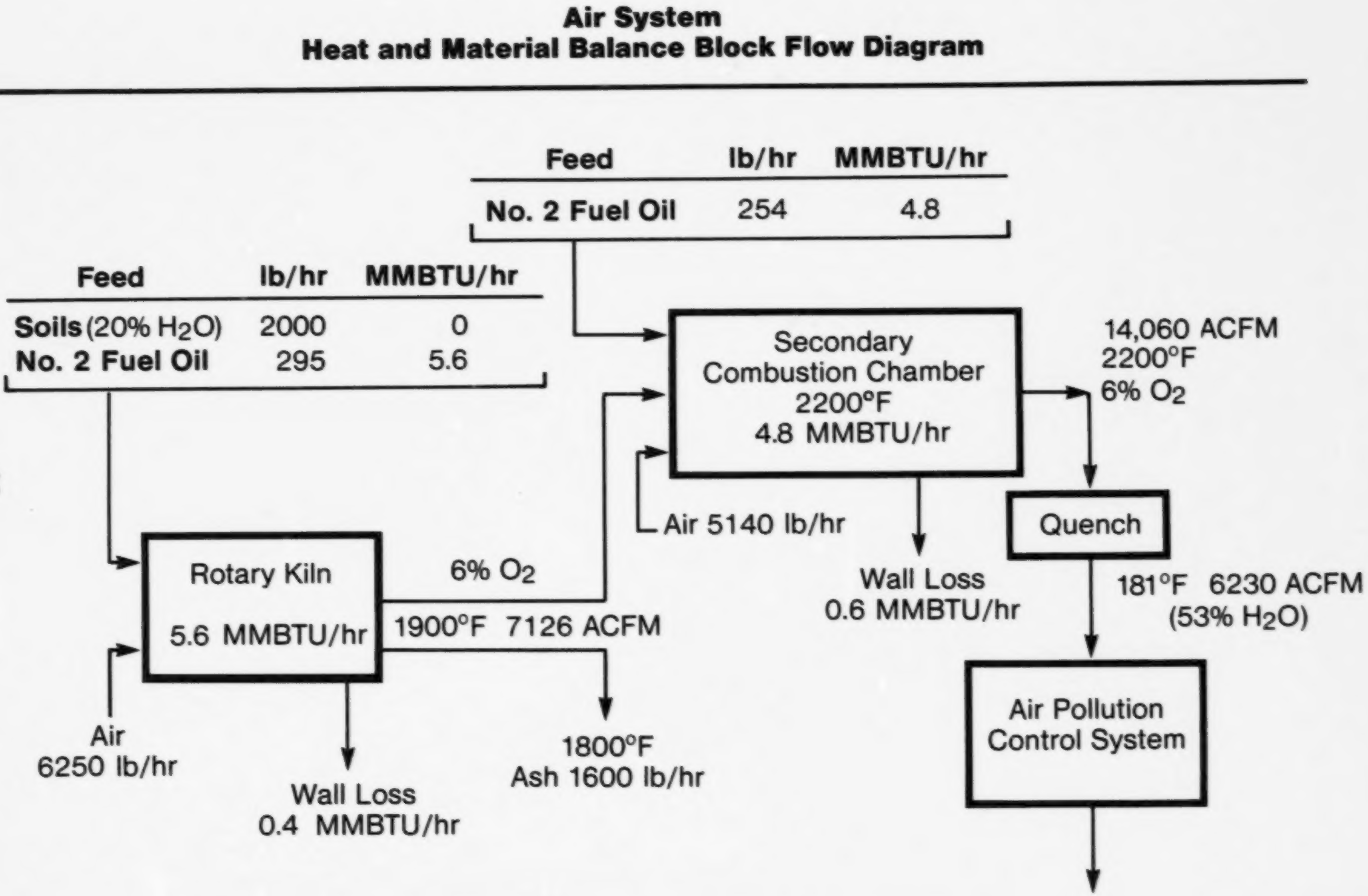

Air System
Heat and Material Balance Block Flow Diagram
Feed
lb/hr
MMBTU/hr
No. 2 Fuel Oil
254
4.8
Feed
lb/hr
MMBTU/hr
Soils (20% H2O)
2000
0
No. 2 Fuel Oil
295
5.6
Secondary
Combustion Chamber
2200°F
4.8 MMBTU/hr
14,060 ACFM
2200°F
6% O2
Quench
Air 5140 lb/hr
Wall Loss
0.6 MMBTU/hr
181°F 6230 ACFM
(53% H2O)
Rotary Kiln
5.6 MMBTU/hr
6% O2
1900°F 7126 ACFM
Air
6250 lb/hr
Wall Loss
0.4 MMBTU/hr
1800°F
Ash 1600 lb/hr
Air Pollution
Control System

Figure 4. Air system heat and material balance.

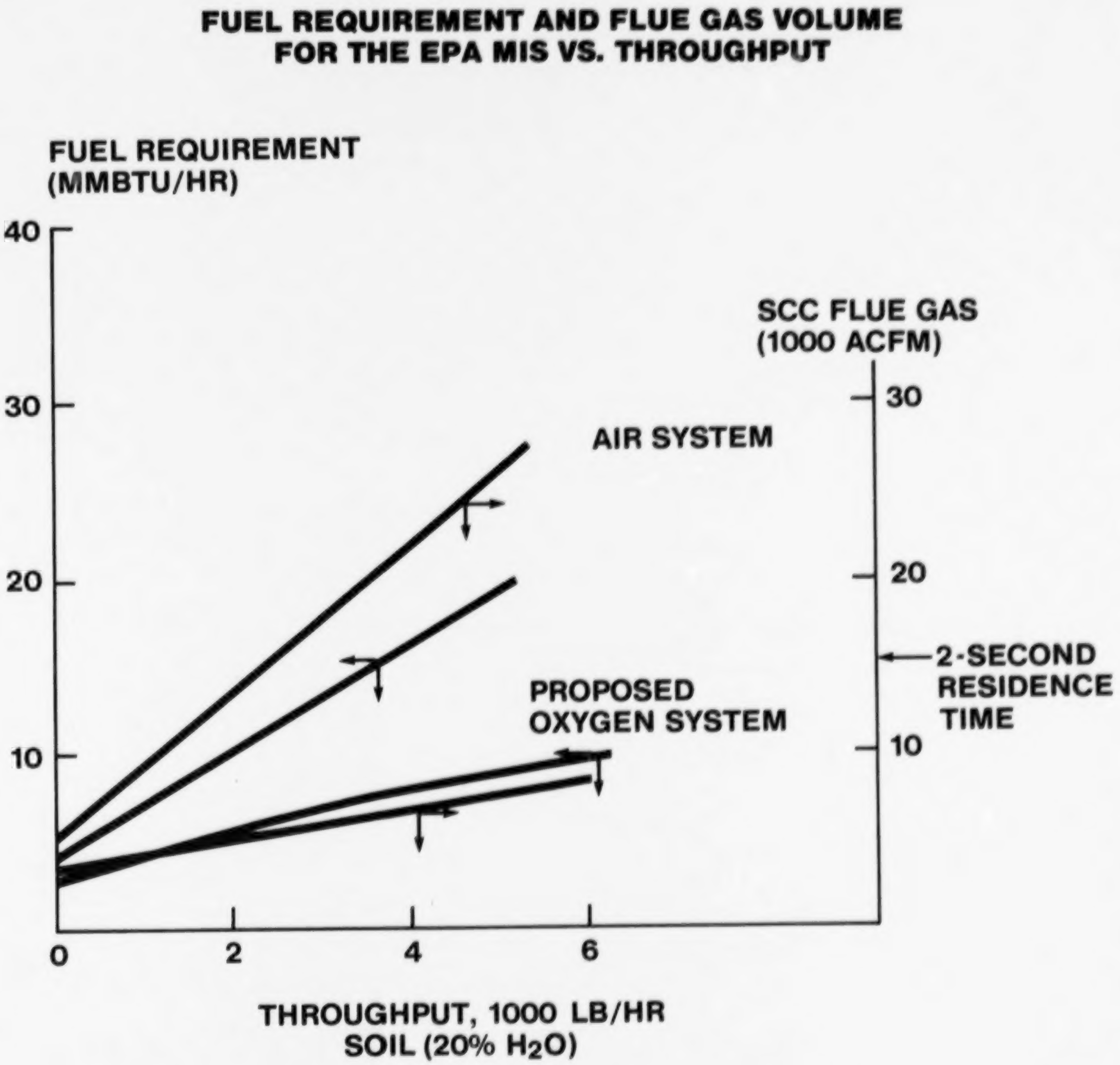


Figure 5. Comparison of fuel requirements and SCC flowrates between air and oxygen systems. (Courtesy of Union Carbide Corporation)

Figure 6 describes a partial heat and material balance for the MIS when using 100% oxygen to sustain combustion and processing 4000 lb/hr of contaminated soil with 20% moisture. Figure 7 highlights the differences in gas volumetric flow rates when firing the kiln on air as compared to 100% oxygen.

When processing 4000 lb/hr of soil at 20 wt% water with 100% oxygen, the kiln exit velocity is around 2.7 ft per sec (fps) compared with 6.0 fps when processing only 2000 lb/hr of dry soil using air. The 2:1 reduction in velocity will help to reduce the particulate carryover problems further downstream in the MIS.

Oxygen Burner Criteria

The major considerations for selection of an oxygen burner were flame temperature and mixing characteristics. The use of oxygen could increase flame temperatures significantly. While increases in flame temperature are moderated by dissociation effects, it was felt that an additional 300°F to 400°F flame temperature difference would have a proportional effect on raising the NO_x levels and it would also increase the kiln shell temperature. This would increase the potential for kiln distortion, and could also increase the maintenance on the seals, refractory, etc.

To minimize temperature increases, rapid mixing of fuel, oxygen, and recirculated combustion products were needed. High momentum is needed to produce good mixing. This may be obtained through either mass or velocity or a combination of both. Due to lack of nitrogen, the oxygen burner must rely mostly on the velocity to carry out mixing.

Linde "A"^{R} Oxygen Burner

The Linde "A"^{R} burner system (from Union Carbide) was selected based on Union Carbide's experimental data which substantiated low NO_x levels and lower flame temperatures. This burner, which uses 100% oxygen, replaced one of the conventional air burners. A schematic of the "A" Burner is shown in Figure 8. More details about the "A" Burner can be found in References 6, 7, and 8. A unique feature of this burner is that it produces a flame having a temperature comparable to the conventional air burner flame temperature. This is accomplished by aspirating the furnace gases into the oxidant jets prior to mixing with the fuel as shown in Figures 8 and 9 by the arrows. These high velocity oxygen jets result in vigorous recirculation within the furnace which should produce a uniform temperature distribution within the kiln. By maintaining sufficient distance between the oxygen jets and fuel supply, enough of the furnace gases are aspirated into the oxygen jet prior to mixing with the fuel so that the resulting flame temperature is reduced to values substantially below the theoretical flame temperature (Figure 10).

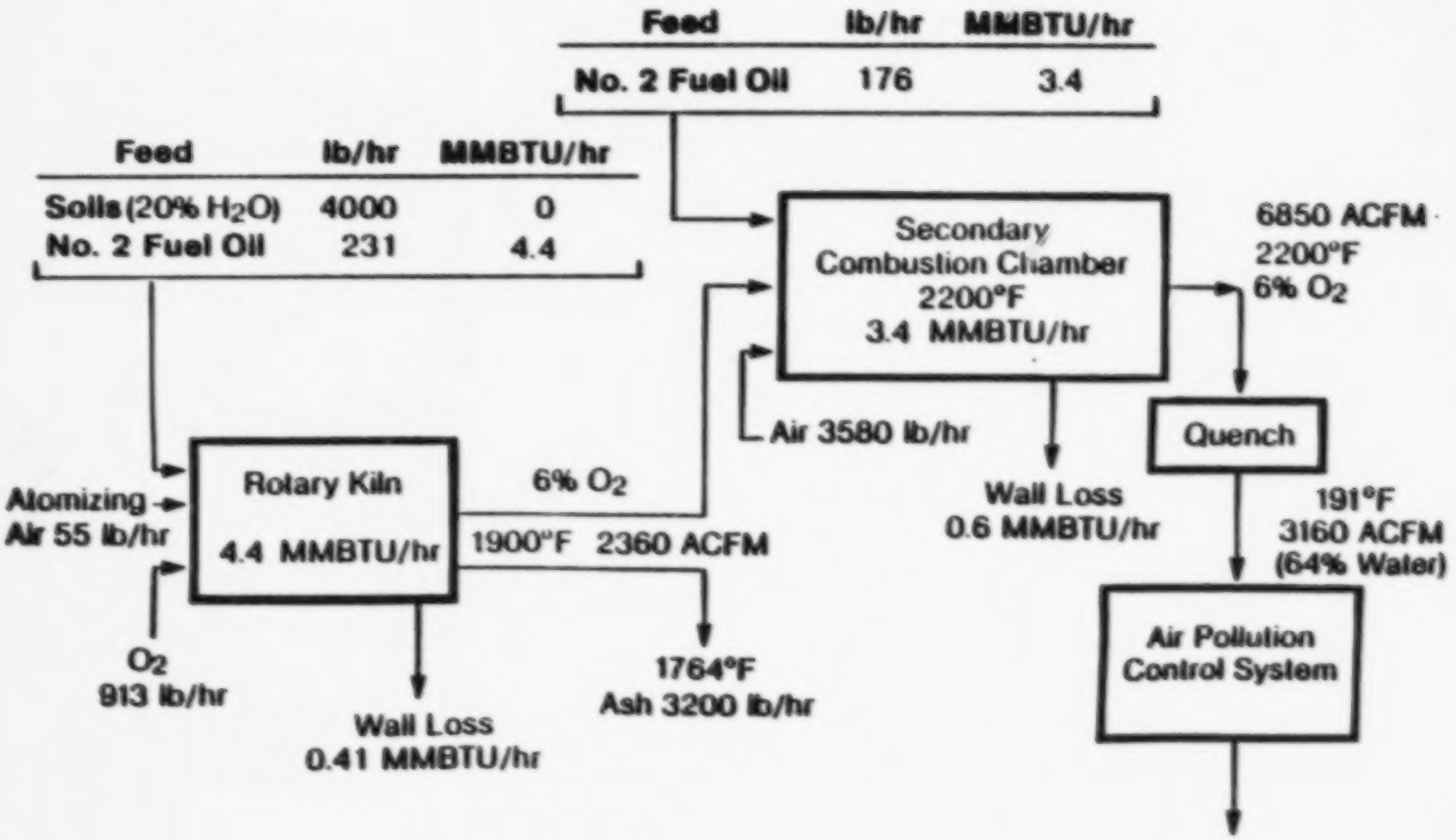

Feed
lb/hr
MMBTU/hr
No. 2 Fuel Oil
176
3.4
Feed
lb/hr
MMBTU/hr
Soils (20% H_2O)
4000
0
No. 2 Fuel Oil
231
4.4
Secondary Combustion Chamber
2200°F
3.4 MMBTU/hr
6850 ACFM
2200°F
6% O_2
Air 3580 lb/hr
Quench
Atomizing Air 55 lb/hr
Rotary Kiln
4.4 MMBTU/hr
6% O_2
1900°F 2360 ACFM
Wall Loss
0.6 MMBTU/hr
191°F
3160 ACFM
(64% Water)
Air Pollution Control System
O_2
913 lb/hr
Wall Loss
0.41 MMBTU/hr
1764°F
Ash 3200 lb/hr

Figure 6. Oxygen system heat and material balance.
(Courtesy Union Carbide Corporation)

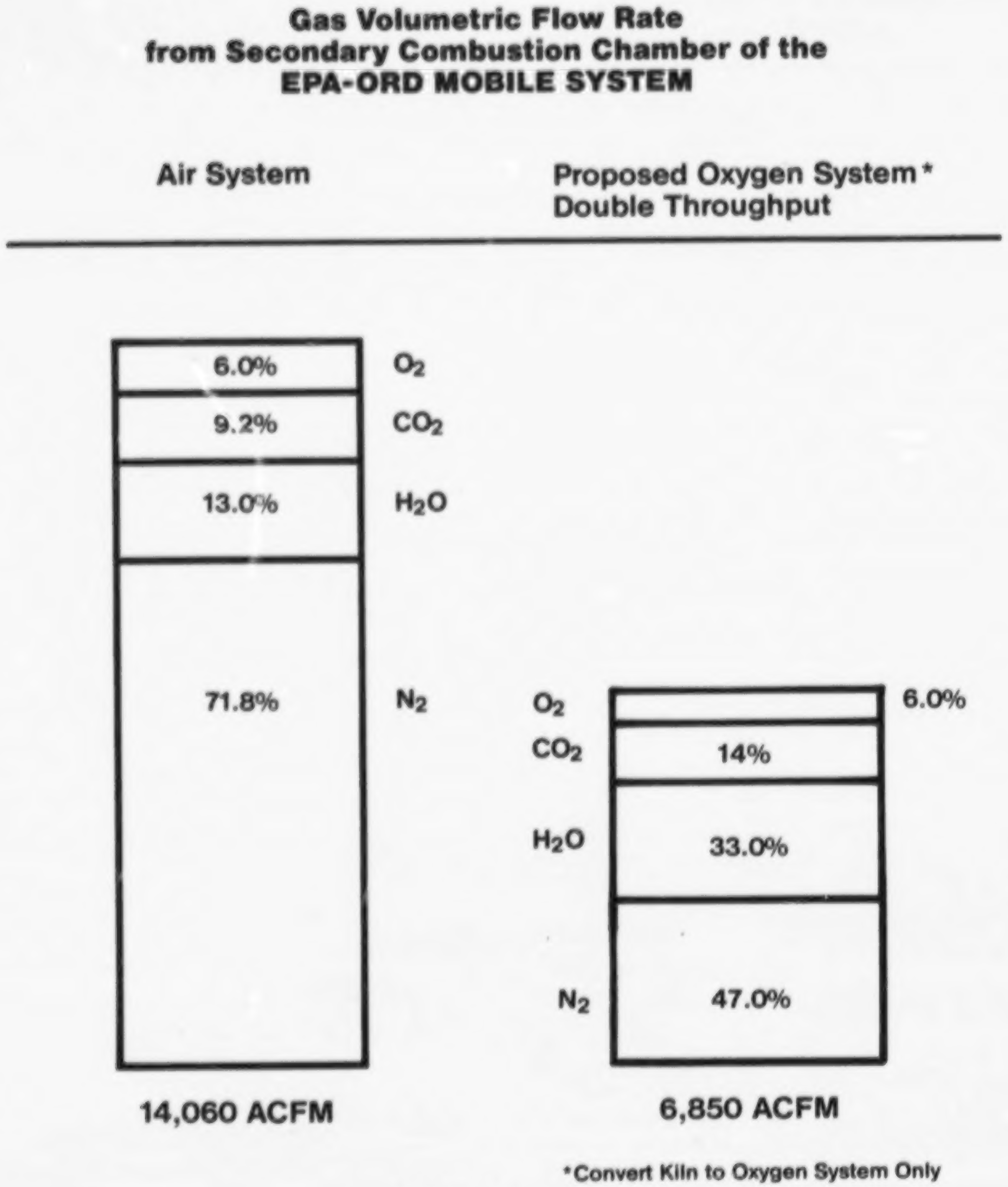
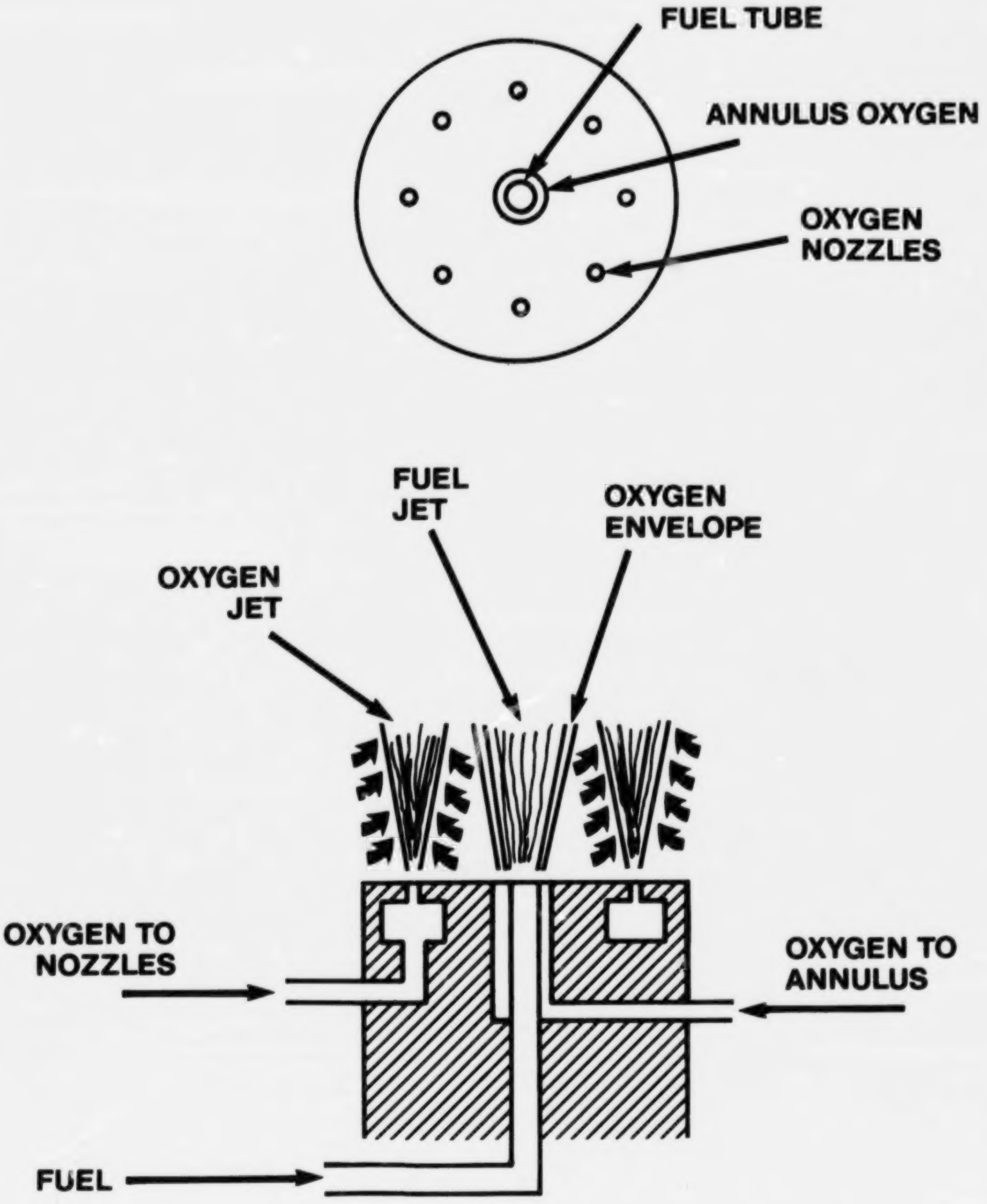


Figure 7. Comparison of SCC flowrates and compositions between air and oxygen systems. (Courtesy Union Carbide Corporation)



Schematic Sketch of the A-Burner

FUEL TUBE
ANNULUS OXYGEN
OXYGEN NOZZLES
FUEL JET
OXYGEN ENVELOPE
OXYGEN JET
OXYGEN TO NOZZLES
OXYGEN TO ANNULUS
FUEL

Figure 8. Schematic sketch of the oxygen burner. (Courtesy Union Carbide Corporation)

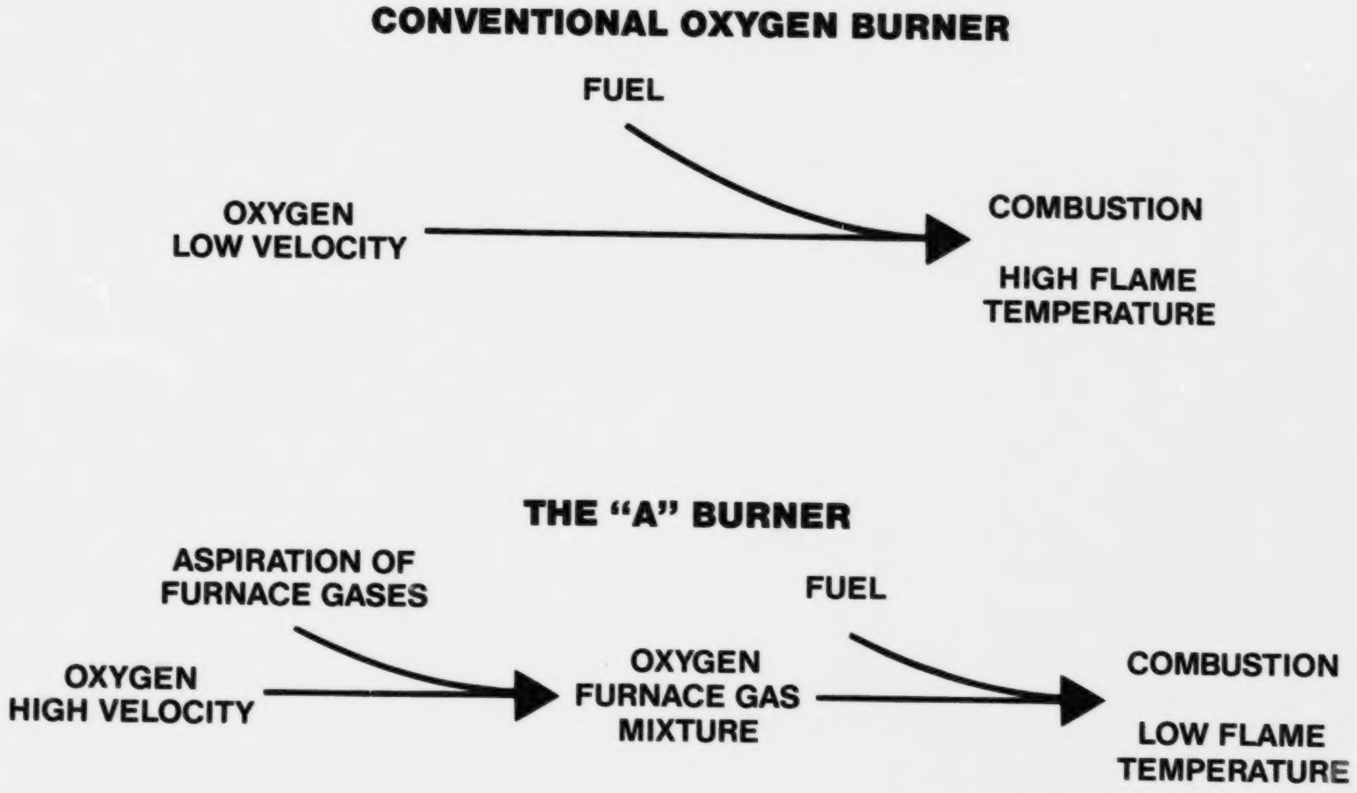

CONVENTIONAL OXYGEN BURNER
FUEL
OXYGEN LOW VELOCITY
COMBUSTION
HIGH FLAME TEMPERATURE
THE "A" BURNER
ASPIRATION OF FURNACE GASES
FUEL
OXYGEN HIGH VELOCITY
OXYGEN FURNACE GAS MIXTURE
COMBUSTION
LOW FLAME TEMPERATURE

Figure 9. Comparison of oxygen burner types.
(Courtesy Union Carbide Corporation)

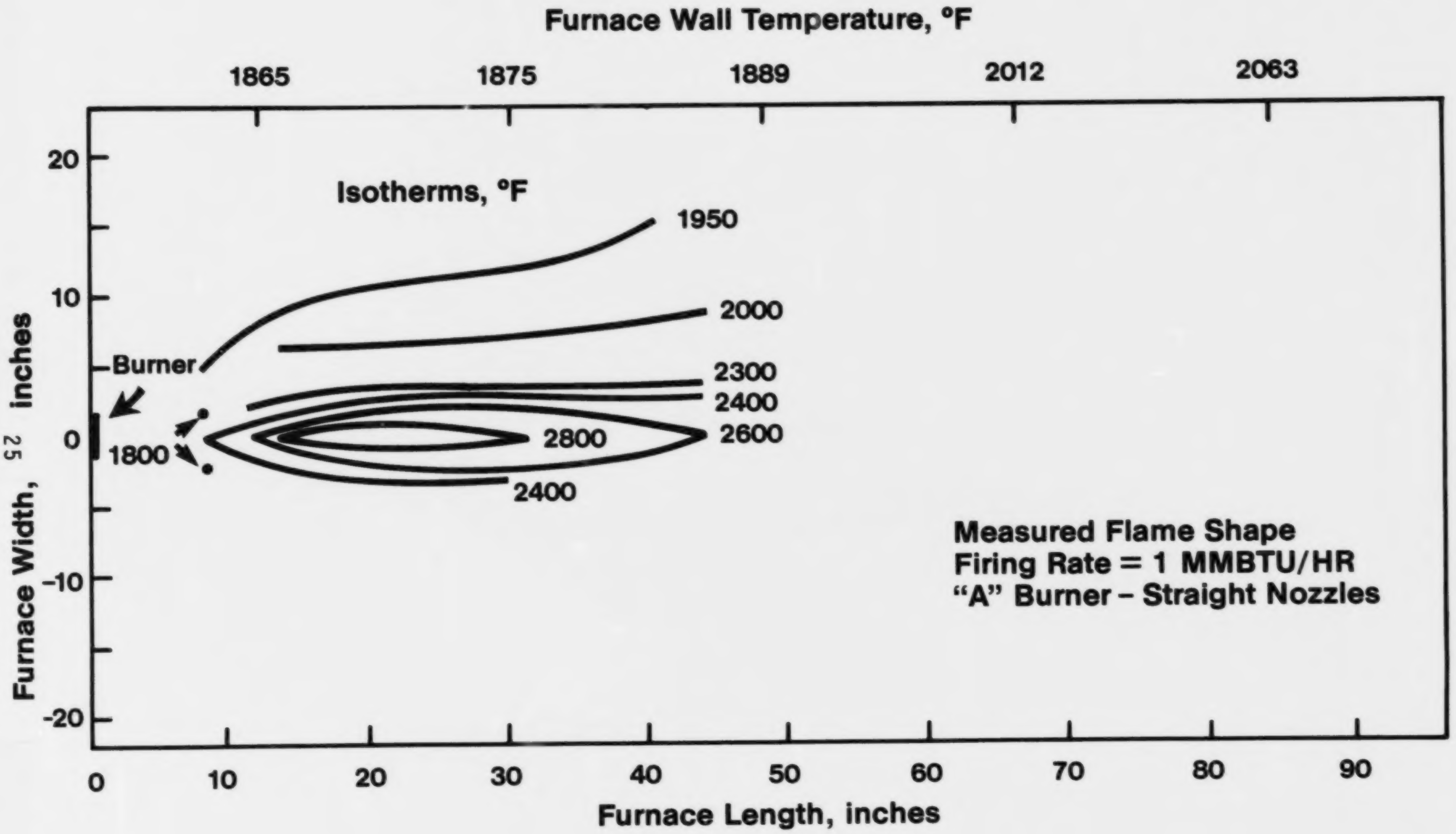


Figure 10. Flame temperature profile for Linde "A"^{R} Burner. (Courtesy Union Carbide Corporation)

In addition to the burner, Linde provided flow control piping skids and a microprocessor based control console to enhance the safety of the operation.

Feed System

The other capacity-limiting factor was easily eliminated by increasing the volume of the ram feed trough from 0.5 ft^3 to 1.2 ft^3. The original ram feed pushed 0.5 ft^3 of soils into the kiln every 50 seconds. Based on a soil bulk density of 70 lb/ft^3, 2520 lb/hr of material would be loaded into the kiln. To increase the soils throughput, the size of the feed trough and ram were changed from a 5-in radius semicircle to a 12-in deep by 10-in-wide (to match weigh hopper width) rectangular shape. This increased the feed capacity to 5000 lb/hr with the same cycle time. The change also provided sufficient space to prevent solids, especially drum shards, from jamming between the ram and the trough cover plate.

The ram feed system of the MIS was equipped with a 2-in diameter auger to return the back spillage to the front of the ram; however, it was not capable of handling fine particulate soils, i.e., sandy river loam. When processing such soils, the back spillage became so voluminous that the ram was prevented from retracting back past the weigh hopper feed opening. This necessitated a shutdown and clean-out by personnel dressed in protective clothing, due to the toxicity of the unprocessed soil.

To alleviate the jamming due to back spillage, a tubular conveyor capable of removing and returning fine particulate soils to the front of the ram was installed. Feed system reliability was thus improved.

Cyclone

The entrainment of solids from the kiln was a persistent operating problem that severely limited the MIS on-stream availability. EI recommended installing a refractory-lined cyclone at the outlet of the kiln to remove most of the particulate carryover and thus minimize or eliminate the solids buildup problems in the SCC, the process water system, and downstream equipment.

The cyclone was designed based upon field operating data. Particulate loading was based on the measured carryover from the kiln (equal to 25% of the feed). The cyclone was designed for a flue gas flow of 7000 ACFM at $1900^{o}F$ and 40 in of water negative pressure. This considered that 25% of the kiln oxygen requirements would be supplied by air. To predict performance, particle size distribution measurements were made by the laboratory at Foster Wheeler USA on fines that accumulated in the SCC and were collected in the hydrocyclone system. SCC particulates were in the 0.1 to 200 micron range with the mean particle size ranging from 57 to 128 microns depending upon the soil being processed. The mean particle size of the hydrocyclone material was 23 microns. At the above conditions, the cyclone was expected to remove 90% of the total particulate matter and 93% of the particulate matter sized greater than 20 microns. With a cut diameter (size particle removed at 50% or greater efficiency) of 4 or 5 microns, it was anticipated that solids passing through the cyclone would be carried through the SCC with minimal deposition.

The cyclone is constructed of carbon steel (SA-516-70) lined with a dual layer of refractory to protect against corrosion and high temperature. It operates as follows: A high velocity stream of particulate-laden flue gas enters tangentially at the top of the unit. The inertia of the particles forces them to the outside wall where they separate from the gas. The particles move in a circular pattern and are discharged into a conical section of the cyclone. The cleaned flue gas disengages from the solid near the start of the conical section, spirals upward, and is discharged at the top of the unit. The collected particulates exit from the bottom of the cyclone through two automated flapper valves and then are transferred by a screw auger to ash collection drums.

Secondary Combustion Chamber

The SCC is a horizontal, cylindrical, refractory-lined chamber (531 ft^3) equipped with two burners, mounted on either side of the chamber. The burners are mounted so that they fire tangentially into the SCC, thus adding to the turbulence and mixing.

Because of the addition of the cyclone and oxygen firing at the upstream side, no major construction or operational changes were required for the SCC. The residence time, turbulence, and temperature required for incineration remain adequate and could, if necessary, be adjusted to insure permit compliance by one or more of the following:

- Increase combustion and/or tuyere air (supplied over the bed of solids) to the kiln

- Increase combustion air to the SCC

When operating the kiln with only the "A" burner at 100% oxygen, the Reynolds number in the SCC, assuming axial flow, is 11,900, which indicates a very significant amount of turbulence exists. Thus, the requirements to insure an adequate DRE are retained: 4.8-sec residence time (2 sec minimum required), turbulence (11,900 Reynolds number), and temperature at 2200°F.

Particulate Emission Control

Since the CHEAF was responsible for a significant portion of the downtime, a design study was conducted to select another particulate emission control device. Different types of particulate scrubbers were briefly considered. Even though these devices are available in a wide range of designs, sizes, advertised performing capabilities, and at a wide range of capital and operating costs, most of them simply use one or more of the following basic mechanisms for particle collection from gas streams: (1) gravitational sedimentation; (2) centrifugal deposition; (3) inertial impaction and interception; (4) Brownian diffusion; (5) thermophoresis; (6) diffusiophoresis; (7) electrostatic precipitation; and (8) particle growth.

Based on an analysis of the available pressure drop, space limitations, and varied operating levels expected, the technical evaluation of the scrubber equipment focused on two basic types - Venturi and Wet Electrostatic Precipitator (WEP).

Venturi--

The venturi-type scrubber was eliminated since it could not provide adequate removal efficiencies without high pressure drops (60 to 100 inches of H_2O). Therefore, Venturi scrubbers were evaluated in conjunction with providing a new fan. The total added cost penalty ($100,000 to $125,000 for fan and drive) made the Venturi scrubber unattractive.

Eductor--

The eductor-type unit is similar in nature to the venturi type, but derives only part of the required energy from the I.D. fan, the rest comes from the eductor effect of the water jet. Even with that advantage, the unit requires a pressure drop at, or in excess of, the maximum available (even if the MX Scrubber were removed) to meet the MIS design conditions. Since the MIS could be operating most of the time at a lower flow rate than design, the eductor-type scrubber will suffer an efficiency loss with reduced velocity (energy). Therefore, the eductor unit required a recycle of cleaned flue gases to maintain velocity and separation efficiency. In addition, a demister would be required for mist separation.

Due to the pressure drop limitation and an inadequate safety margin to account for the uncertainties of actual MIS operations, the eductor unit was not recommended.

Wet Electrostatic Precipitator (WEP Scrubber)--

The wet electrostatic precipitator (WEP) was chosen because of its ability to remove submicron-sized particles efficiently and its low pressure drop requirement. The ability to remove submicron particles is an advantage for processing wastes, which contain volatile heavy metals such as lead. The low pressure drop requirement permitted the use of the original I.D. fan, thus the cost penalty for a new fan and driver was avoided. A wet electrostatic precipitator relies on electrical energy to collect particles by attracting them to a grounded surface. A WEP supplied by Beltran was recommended as being the best technically acceptable unit capable of meeting the process and space requirements. The operation and design of the WEP is described below.

The gas exiting the SCC is quenched by water sprays prior to flowing through the quench sump and on to the WEP. Upon entering the WEP the gases are further conditioned by water sprays. The gases flow past fogging nozzles into an "egg crate" grid of electrically grounded ducts of square cross-section. Each square duct houses a single needle/spike at its center which runs the length of the duct, parallel to the grounded walls.

The needle/spike imparts a like negative charge on a particle as it begins to travel inside the duct. Repulsion forces (due to the likeness in charge) interacting between the needle/spike and the particle, as well as forces of attraction between particle and grounded walls (grounded walls are "oppositely charged" as far as the particle is concerned) cause the particle to drift toward the walls of the duct where collection occurs. This "push - pull" effect produces the electrostatic precipitator's high collection efficiency and low power requirements.

The materials of construction of the WEP and the ducts carrying the clean gases to the existing MX Scrubber are fiberglass reinforced plastic (FRP). Further description of the WEP follows.

The electrostatic precipitator consists of four major assemblies:

- The fiberglass-reinforced plastic (FRP) housing is designed to resist highly corrosive environments while providing the structural strength necessary to support the collector and ionizing grids.
- The collection grid surfaces are made of conductive FRP sheets which are arranged in an interlocked grid that is operated at ground potential. The surfaces attract the negatively charged particles which are then continuously washed away.

- The ionizing rods and grid are operated at a high negative potential to the collecting plates. The rods produce a corona which imparts a negative charge on the particles in the gas stream causing them to move toward the collecting plates. The rods were originally made of conductive FRP but were changed to 301 stainless steel during August 1988 to reduce maintainance.

- The spray headers consist of three independent systems: The fog headers are used to condition and cool the gases as they enter the collector tubes. The upper wash headers are used to clean the collector plates. The wash headers are turned on periodically to clean the collector tubes. The lower saturation section consists of a packed tower and spray nozzles to insure the gases are neutralized, cooled, and saturated.

The solids collected by the water in the WEP were removed in the water treatment system as separator sludge and were sent to a landfill after analysis for chromium, mercury, and selenium. An exception was the separator sludge generated from processing brominated sludge. This material was recycled to the kiln. The treated water is returned to the WEP except for approximately 1% blowdown.

I.D. Fan--

Replacement of the CHEAF by the WEP eliminated the high air infiltration rate and pressure drop buildup due to plugging of the filter media. Therefore, the costly replacement of the ID fan, which maintains MIS vacuum, was avoided. However, to improve the pressure control throughout the MIS, a recirculation duct with a valve was installed between the exhaust stack and suction to the I.D. fan.

Less Critical Modifications

Other less-critical modifications also were made to the MIS system. These include: modifications of the quench sump; addition of a Monarch^R CPI separator, which replaces the hydrocyclones to remove the particulates from the process water; addition of a water softener; addition of new instruments; and numerous instrument replacements.

MODIFICATIONS IN 1988

Although the 1987 modifications increased both the capacity and the reliability of the MIS, operating experience during 1987 showed that the increased capacity and reliability were obtained for "ideal" feeds consisting of relatively dry soils having about 20% moisture content. This operating experience as well as subsequent operating experience in 1988 with brominated sludge showed that further modifications were required to handle problems associated with feed characteristics of other wastes such as trash, plastics, sludges, etc.

Modifications performed in 1988 included the addition of a conveyor belt system to bring feed material to the shredder, the replacement of the doctor blade in the main feed conveyor with an adjustable roller, addition of a television camera at the discharge end of the main feed conveyor, redesign and repair of the ash gates, addition of knock-out ports in the ducts between the kiln and SCC, addition of a deep bed filter for separator sludge, and changes to the pH control system. At the time of closure operations in 1989, all the modifications had increased the on-stream time to 80% and had decreased the cost of incineration from $2800 per ton to $1100 per ton. The changes to the system and their effect on overall performance are discussed in greater detail in Section 8.

SECTION 4

COMPLIANCE TESTING OF THE MODIFIED SYSTEM

SYSTEM PERMITTING AT INCREASED CAPACITY

Applications for permit modifications to both the RCRA and air permits were filed jointly with the Missouri Department of Natural Resources (MDNR) and EPA Region VII [9]. The requests for permit modifications coincided with renewal activities for each of the permits. Since MDNR had not received final authorization to administer dioxins under the federal program, EPA and MDNR jointly issued the final RCRA permit [10], and MDNR issued the revised air permit.

The modified permits required compliance testing of the MIS for particulate emissions at the higher feed rates. The RCRA permit was structured so that the modified incinerator had to pass a particulate test at a solids feed rate of 2000 lb/hr before being allowed to attempt passing the test at a feed rate of 3000 lb/hr. This staging provision continued up to a feedrate of 5000 lb/hr. Destruction and Removal Efficiency (DRE) testing was not mandated by the regulatory agencies for several reasons, which are explained below.

The criteria set forth by the revised operating permit required compliance testing only in areas that were affected by the modifications as follows:

- o Particulate testing was needed due to the capacity increase and the replacement of a cleanable high efficiency air filter (CHEAF) with a cyclone and wet electrostatic precipitator (WEP). (See Section 3.)
- o Verification that the byproduct residues still passed the hazardous waste delisting criteria was also necessary due to the large capacity increase.
- o DRE tests were not needed because the 2,3,7,8-tetrachlorodibenzo-p-dioxin input rate was still much lower than that demonstrated during the 1984/1985 trial burn [11]. The flue gas temperatures in the rotary kiln and the secondary combustion chamber (SCC) were kept unchanged. Gas residence times in the SCC also remained unchanged, although feed capacity had doubled.

As discussed below, the modified MIS passed all required compliance testing during the time period from June 15 to June 18, 1987 (memorandum F. Freestone to L. Harrington, "Residue Verification Analysis and Particulate Emission Compliance Demonstration for the Modified Mobile Incineration System at Denney Farm", July 23, 1987).

Particulate Testing

According to the permit issued by The Missouri Department of Natural Resources (MDNR) and EPA Region VII, particulate testing consisted of four tests using dioxin-contaminated Denney Farm soil [10]: a test at the previous 2000 lb/hr maximum soil feedrate during day one, a test at 3000 lb/hr during day two, and tests at 4000 lb/hr during days three and four. Particulate emissions had to be within the regulatory limit of 0.08 gr/dscf (corrected per the Facility Operating Permit requirements) before testing could proceed at the next higher feedrate. This required that the stack testing crew weigh and dry the filter and probe rinse in the field.

As shown below, the MIS demonstrated compliance well within the particulate emission standard of 0.08 gr/dscf for all solids feedrate cases. The particulate emissions are corrected per the Facility Operating Permit, which includes a factor for oxygen enrichment. The results, corrected to the normal 7% excess oxygen, are presented for comparison. The factor for oxygen enrichment was unique to the MIS because of its oxygen burner system. (See discussions in Section 3.) The normal correction to 7% excess oxygen for incinerators is based upon a target of approximately 50% excess air. When oxygen enrichment is used, an excess air of 50% is achieved at higher levels of excess oxygen. The operating permit recognized this scientific principle. A sample calculation for the oxygen enrichment correction factor is presented in Appendix A.

PARTICULATE EMISSIONS RESULTS - (gr/dscf)

Nominal Solids Feedrate lb/hr	Uncorrected Emissions	Corrected Per Facility Permit	Corrected To 7% Oxygen
2000	0.0059	0.0077	0.013
3000	0.0235	0.028	0.051
4000	0.0176	0.021	0.035
4000	0.0186	0.023	0.037

Residue Verification Analyses

As discussed below all residue samples passed the verification analyses for target analytes specified by the Office of Solid Waste (OSW). The target analytes required by the verification analyses consisted of dioxin and furan homologues, certain volatile and semivolatile (base/neutral/acid extractable - BNAs) compounds, PCBs and metals. Verification criteria required that the concentrations of the target analytes in the residue streams be lower than the delisting concentrations given in Table 2. If a delisting concentration was below the detection limit of the analytical method, the constituent had to be non-detected (ND) to pass

TABLE 2. DELISTING CRITERIA FOR VERIFICATION ANALYSES AND DETECTION LIMITS

Constituent	Solids (ppm)	Water (ppb)	SW-846 Method
Dioxins/Furans	(b)	(b)	
TCDD/TCDF	(a) (0.001)	(a) (0.01)	8280
PCBs	0.03 (0.05)	0.1 (0.3) (c)	8080
Organics			
Volatiles (VOAs)			
Carbon Tetrachloride	0.17	5.0	8240
Semivolatiles (BNAs)			
Benzo(a)pyrene (e)	0.038 (0.2)	0.019 (10)	8270
Benzo(a)anthracene (e)	0.097 (0.2)	0.1 (10)	8270
Chrysene	15	3 (10)	8270
Dibenzo(a,h)anthracene (e)	0.007 (0.2)	0.011 (10)	8270
Indeno(1,2,3-cd)pyrene (e)	29	3 (10)	8270
Benzo(b)fluoranthene (e)	0.16 (0.2)	0.3 (10)	8270
Hexachloroethane	67	400	8270
2,3,4-Trichlorophenol	(d) (1.0)	(d) (50)	8270
2,4,5-Trichlorophenol	17000	50000	8270
2,4,6-Trichlorophenol	0.3	30	8270
2,5-Dichlorophenol	(d) (0.2)	(d) (10)	8270
3,4-Dichlorophenol	(d) (0.2)	(d) (10)	8270
2,3,4,5-Tetrachlorophenol	(d) (1.0)	(d) (50)	8270
2,3,4,6-Tetrachlorophenol	636	5000	8270
1,2,4,5-Tetrachlorobenzene	64	200	8270
1,2,3,5-Tetrachlorobenzene	(d) (1.0)	(d) (50)	8270
Hexachlorophene	(d) (10.0)	(d) (500)	8270
EP TOXICITY METALS PLUS NICKEL			
Arsenic			
Barium			
Cadmium			
Chromium	NA	680	6010
Lead			
Mercury	0.044	30	7040
Selenium	0.22	140	6010
Silver			
Nickel			

(continued)

TABLE 2 (Continued)

(a) All dioxin levels must be below the lowest achievable detection limits using the appropriate SW-846 Method.

(b) All values listed in parenthesis are the detection limits for the applicable SW-846 Method with a 24-hr turnaround analysis.

(c) Detection limit is 0.3 ppb for Arochlor 1256 and 1260. Detection limit for Arochlor 1242 is 0.1 ppb.

(d) Regulatory standards are not yet available for these constituents.

(e) All values of this compound must be non-detect.

the verification analysis. Analyses had to be conducted per the appropriate SW-846 Methods, listed in Table 2.

To demonstrate validity of the analyses, Quality Assurance/Quality Control (QA/QC) samples were analyzed. These consisted of a matrix spike duplicate pair for each sample matrix, appropriate method blanks, and laboratory control and check samples.

Four sets of residue samples were taken and analyzed, a set of samples was collected from the residues generated during each particulate test. Each sample set consisted of four matrices: kiln ash, cyclone ash, CPI separator sludge, and purge water. Although not required by the permit, water samples were taken from the quench sump. Since the initial contact between the process water and the SCC outlet gas occurs in this part of the system, the water in the quench sump has the highest concentration of impurities and hence it has the highest probability of containing organics. A summary of the results of the verification analyses for each sample matrix is presented below.

Kiln Ash--

All analytical results on the four kiln ash samples showed that all target analytes were either non-detect or below the delisting criteria shown in Table 2. Quality Control data showed that recovery of spiking compounds was adequate proving that the analyses would detect the hazardous compounds if they were present.

Purge Water--

All analytical results on the four purge water samples showed that most target analytes were either non-detect or below the delisting criteria shown in Table 2. However, three of the four water samples contained trace amounts of octachlorodibenzo-p-dioxin (OCDD) at levels of 0.57 to 5.1 parts per trillion (ppt). OCDD does not pose a hazard to the environment [13]. Quality Control data showed that recovery of spiking compounds was adequate proving, that the analyses would detect the hazardous compounds if they were present.

Quench Water--

All analytical results on the four quench water samples showed that all target analytes were either non-detect or below the delisting criteria shown in Table 2, with the exception of selenium. One sample contained 0.16 ppm of selenium, which is slightly higher than the delisting criterion of 0.14 ppm. However, the quench sump water is not discharged from the system and the selenium concentration of the storage tank containing all of the wastewater from the particulate test period was less than one part per billion (ppb).

Cyclone Ash and CPI Separator Sludge--

All analytical results on the four cyclone ash and the four CPI Separator sludge samples showed that all target analytes were either non-detect or below the delisting criteria shown in Table 2. Quality Control data showed that recovery of spiking compounds was adequate, proving that the analyses would detect the compounds if they were present.

SECTION 5

SHAKEDOWN TESTS FOR TRIAL BURN

OBJECTIVES

The shakedown testing was executed during June and July, 1987, to demonstrate that the unit's physical performance under simulated trial burn conditions would be adequate. An additional purpose was to confirm that the unit operated safely with the new Linde "A"^{R} oxygen burner system and other modifications added during the shutdown period.

RESULTS

As described below, the shakedown testing demonstrated that the MIS could operate successfully under most of the trial burn conditions. However, it revealed that particulate emissions were significantly above regulatory limits when there were high organic chloride loadings in the feeds. This discovery showed that modifications to the MIS would be necessary to ensure compliance with the particulate emissions criteria at the high organic chloride loading of the trial burn feeds. These modifications caused a delay in the start of the testing program.

The shakedown tests of the MIS demonstrated the following capabilities and weaknesses:

- Inadequacies of the unit to handle high organic chloride loads resulted in noncompliance with particulate emissions standards. This discovery led to the addition of a mist eliminator (a Demister^{R} by Otto York Company) in the outlet of the MX Scrubber to correct the problem, hence saving the expense of a failed trial burn. After installation of the Demister^{R}, particulate emissions were in compliance with permit requirements (0.048 gr/dscf emitted compared to 0.08 gr/dscf allowed) with an organic chloride loading of 180 lb/hr.

- The flame stability tests demonstrated that the unit could successfully handle sudden changes in either oxygen burner fuel flow or waste liquid fuel flow.

- Adequate flame stability also was proven for liquid fuels that simulated trial burn fuel properties at rates up to 400 lb/hr and heat contents ranging from 7000 to 18,000 BTU/lb. This greatly exceeded the trial burn requirements.

- The soil loading tests proved the capability of the MIS to process in excess of 4000 lb/hr of a simulated trial burn soil mixture. Prior to modification the unit was unable to handle this mixture due to jamming of the ram.

- The capability of the unit to simultaneously handle a heat load of 1.33 MM BTU/hr from the soil and 2.25 MMBTU/hr from the waste liquid nozzle also was demonstrated.

- Hydrogen chloride (HCl) removal greater than 99.95% was demonstrated with an organic chlorine loading of 180 lb/hr. This greatly exceeded the permit requirement for 99% acid gas removal.

- DRE for carbon tetrachloride (CCl_4) exceeded 99.99% as required by RCRA.

The tests are discussed in greater detail below.

Soil Loading Tests

Capability of the unit to process more than 4000 lb/hr was demonstrated on several occasions. The first demonstration was carried out with uncontaminated soil (Denney Farm clay) on June 10. Tests performed with dioxin-contaminated soil (Erwin Farm silty soil) on June 17 showed that the unit could meet both residue delisting requirements and particulate emission requirements at 4000 lb/hr a feedrate (See Section 4.) A subsequent test was completed using a simulated trial burn soil consisting of equal parts montmorillonite and Erwin Farm uncontaminated soil. This test showed that the modified unit could process in excess of 4000 lb/hr without the feeding difficulties experienced with this feed prior to modifications of the feeding system.

Control System Response Tests

The capability of the MIS to respond rapidly to large changes in liquid waste fuel input and to large changes in water injection rates was demonstrated during these tests.

Liquid Waste Cycling --

Capability of the liquid waste nozzle to cycle on/off with firing rates up to 2.2 MM BTU/hr was demonstrated on diesel fuel. Oxygen flow responded rapidly and the unit was able to maintain excess oxygen within permit limits.

Water Spray Cycling --

The water spray was cycled on/off with water flows up to 2.5 gpm. The kiln firing rate controls responded adequately to the cycling.

Flame Stability Tests

These tests showed that flame stability of the liquid waste nozzle was adequate for a variety of liquid fuels used to simulate trial burn fuel properties. Stable firing rates above those demonstrated below should be achievable. Test results are as follows:

Diesel Fuel --
Adequate flame stability was demonstrated up to a firing rate of 2.7 MM BTU/hr prior to testing fuels with properties closer to the trial burn liquid waste. These tests revealed that the maximum liquid heat input interlock was set too low for trial burn conditions.

Methanol (CH_3OH)/Carbon Tetrachloride (CCl_4) --
Adequate flame stability also was shown with a mixture consisting of 77% CH_3OH and 23% CCl_4 (7500 BTU/lb heating value) up to a firing rate of 3 MM BTU/hr.

Diesel/Carbon Tetrachloride --
Adequate flame stability was achieved up to 3 MM BTU/hr with a mixture consisting of 62% CCl_4 and 38% Diesel (7500 BTU/lb heating value). Air atomization pressure was optimized during this test.

Methanol/Water --
Satisfactory flame stability was shown up to 2.1 MMBTU/hr with a mixture consisting of 80% methanol and 20% water (7000 BTU/lb heating value).

Trial Burn Heat Input Tests

This test demonstrated the ability of the kiln to simultaneously process soil, which contributes 1.3 MM BTU/hr heat input, and simulated liquid fuel, which contributes 2.2 MM BTU/hr at soil feedrates of 4000 lb/hr. Ash gate temperature remained low (<200 ^{o}F) under the combination of high soil feed rates with high waste-firing rates. This eliminated a concern that ash gate temperature might become excessive under trial burn operating conditions.

Organic Chloride Loading Tests

Through the organic chloride loading tests, a misting problem, attributed to the vigorous reaction between HCl and NaOH in the air pollution control equipment, was detected and corrected. As shown in the particulate emission data presented in Table 3, allowable emissions (0.08 gr/dscf) were exceeded by as much as a factor of three during the first three test runs. The first three tests showed that particulate emissions were proportional to organic chloride loading (expressed as HCl produced), as illustrated in Figure 11.

TABLE 3. PARTICULATE AND HCl EMISSION TEST RESULTS DURING SHAKEDOWN TESTING PERIOD

Test Description:	High Organic Chloride 1	High Organic Chloride 2	High Organic Chloride 3	No WEP (a)	High Organic Chloride 4	High. Organic Chloride 5
Date (1987)	6/18-19	6/28	6/30	7/1	7/20	7/20
Time (Begin-End)	1035-0020	2056-2351	1030-1228	1224-1402	1453-1700	2030-2209
Stack Gas Data						
Gas Temperature (^{o}F)	157	152	157	165	176	175
Gas Velocity (ft/sec)	36.5	33.7	32.8	33.9	24.6	24.9
Flow Rate (acfm)	8770	8080	7890	8140	5900	5980
Dry Standard Flow (dscfm)	4370	4070	3950	4060	2260	2390
Moisture (vol. %)	40.0	39.6	39.3	38.8	52.5	50.5
Carbon Dioxide (dvol. %)	6.4	6.6	6.6	6.8	13.6	11.4
Oxygen (dvol. %)	14.2	14.0	13.6	13.6	7.4	10.4
Particulate Emissions						
Actual (gr/dscf)	0.119	0.142	0.0927	0.0285	0.0506	0.0452
Corrected @ 12% CO_2 (gr/dscf)	0.223	0.257	0.169	0.0503	0.0447	0.0476
Corrected @ 7% O_2 (gr/dscf)	0.245	0.284	0.175	0.0539	0.0521	0.0597
Corrected per Permit (gr/dscf) (b)	0.149	0.177	0.116	------	0.0426	0.0419
Pounds/hour	4.45	4.93	3.14	0.990	0.979	0.925
HCl Formed						
Pounds/hour	162	178	118	0.0	175	189
HCl Emissions (c)						
Pounds/hour	0.06	-	-	-	-	0.002
ppm	2.23	-	-	-	-	0.203
Removal Efficiency (%) (d)	99.96	-	-	-	-	99.99

(a) 2000 lb/hr soil, no chlorides and WEP not operating.
(b) This correction takes into account the use of oxygen. The calculation is presented in Appendix A.
(c) Only two measurements of HCl emissions were required.
(d) Removal efficiency = (HCl formed - HCl out)/HCl formed x 100%.

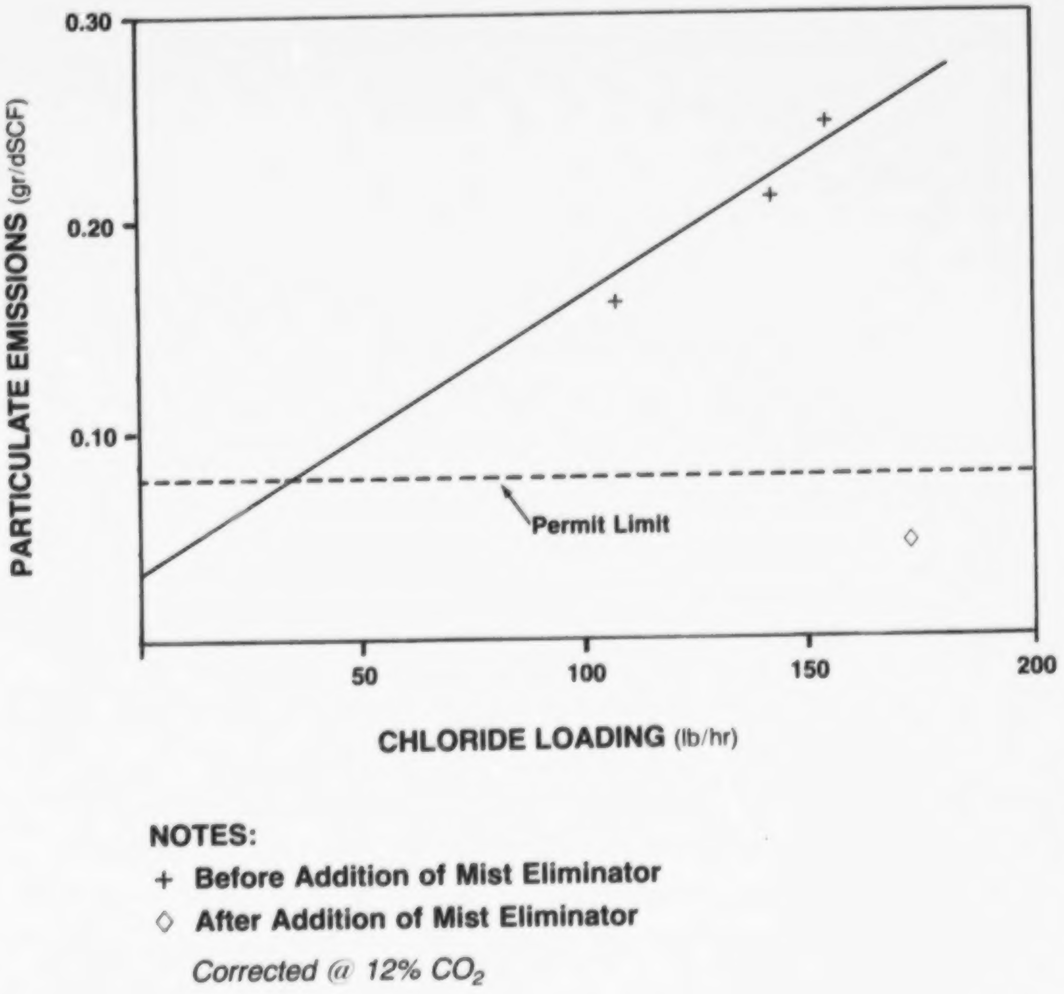


Figure 11. Effect of organic chloride loading on particulate emissions.

To provide insight into how the excess particulate problem was solved, action steps taken to troubleshoot or to mitigate the problem after failure of the first run are described below:

1. For the second test, operating conditions were modified as follows:

   Since production of a fine mist was suspected, the last two banks of spray nozzles in the MX scrubber were deactivated to allow the end of the scrubber to serve as a mist eliminator.

   This change failed to alleviate the problem showing that the scrubber was a poor mist eliminator.

2. Operational changes made prior to the third test were as follows:

   Organic chloride loading was reduced to 118 lb/hr equivalent HCl.

   MX scrubber water flow was modified to minimize salt concentration in the scrubber by changing to softened well water makeup and routing the MX sump discharge to the waste water tanks.

   Particulate emissions were reduced significantly mainly due to the reduction in organic chloride loading. However, the emissions were still double the permit requirements.

3. The particulate filter cake from the first test was analyzed. The analysis, presented in Table 4, showed very high levels of NaCl and excess NaOH. When these results are combined with the particulate emission data from normal operating runs, (See Section 4), mist formation is confirmed.

4. Based upon the above results, a Demister^R consisting of a three-pass chevron unit and an 8.25-inch-thick woven wire pad was installed in the MX scrubber. Installation details are shown in Figure 12.

5. The exit to the emergency vent system was covered with a gasketed board to reduce air leakage. Use of the board does not prevent the vent system from performing its safety relief function. The board is held in place by about 5 inches of water column vacuum, and it falls off when the unit loses vacuum. As shown in Table 3, use of the board to plug the

TABLE 4. RESULTS OF ANALYSES OF METHOD 5 PARTICULATE FILTER CAKES FROM HIGH ORGANIC CHLORIDE LOADING TESTS

Test Description	High Organic Chloride 1	High Organic Chloride 5
Date (1987)	6/18-19	7/20
Total Particulates (g)	0.3412	0.0524
Iron (Fe) (g)	0.0202	0.0057
Chromium (Cr) (g)	0.0022	------
Sodium (Na) (g)	0.1560	0.0175
Chloride (Cl) (g)	0.1367	0.0200
Aluminum (Al) (g)	------	0.0022
As NaCl (g)	0.2253	0.0329
Remaining Na as NaOH (g) (Excess Caustic)	0.1174	0.0079

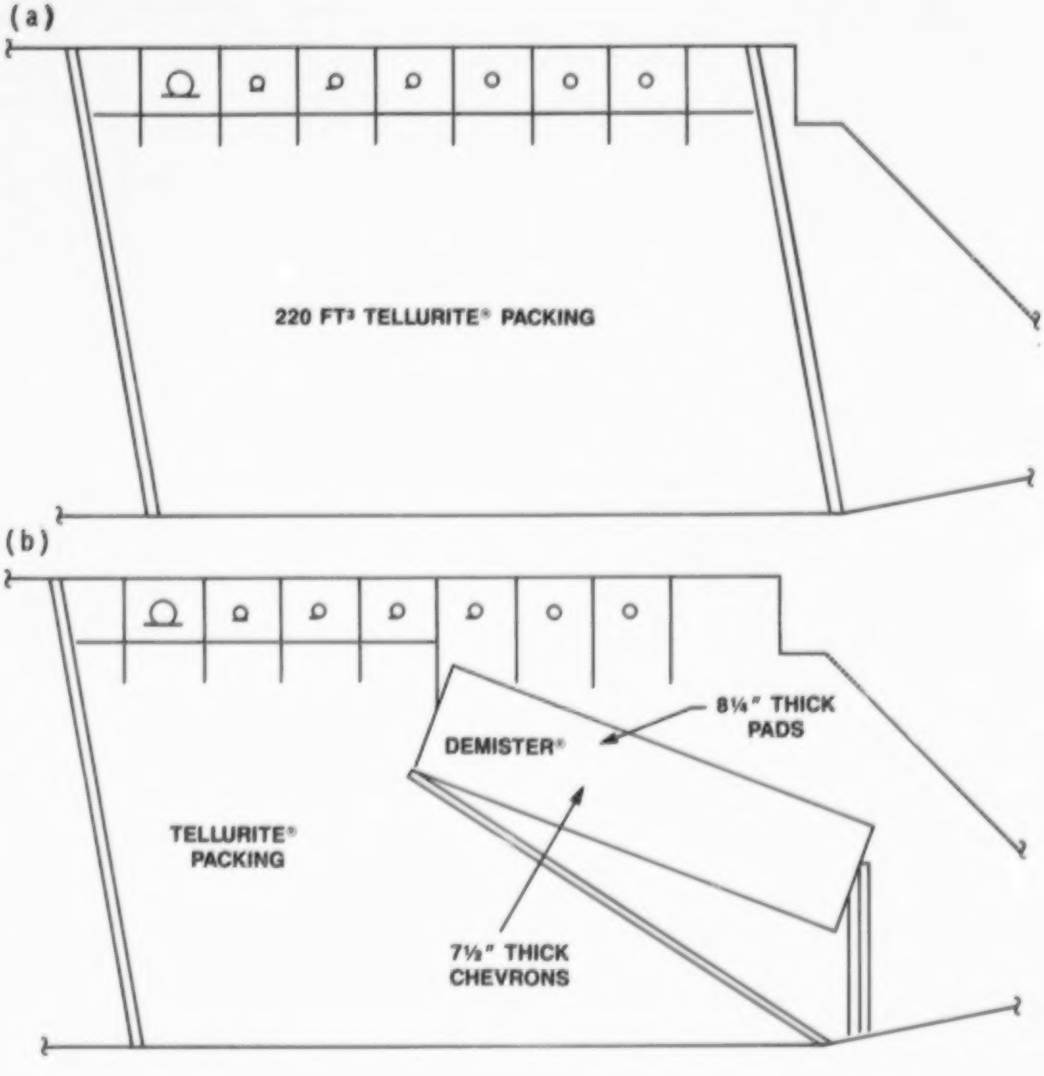

(a)
220 FT³ TELLURITE® PACKING
(b)
DEMISTER®
8¼" THICK PADS
TELLURITE® PACKING
7½" THICK CHEVRONS

Figure 12. MX Scrubber configuration -
(a) Before Demister^{R} installation,
(b) After Demister^{R} installation.

vent reduced leakage substantially by about 2000 scfm. Stack velocity was reduced by 32%. A reduction in stack velocity decreases entrainment of salt-laden droplets.

As shown in Table 3, the mist eliminator (Figure 12) decreased particulate loading so that the unit was able to meet particulate emissions requirements at high organic chloride loadings. This was achieved by reduction in salt carryover. The results of the analysis of the Method 5 particulate filter cake from test 5, given in Table 4, show that carryover of salt and NaOH was reduced by about 67%.

Scrubbing Efficiency

The high organic chloride tests show that HCl removal in the system is excellent. Scrubbing efficiency was greater than 99.95% as shown in Table 3. This high scrubbing efficiency is not surprising since scrubbing occurs at many points in the system including: the quench nozzle, the entrance to the wet electrostatic precipitator, within the precipitator, and finally in the MX scrubber.

The high degree of HCl neutralization enabled the rapid and economic installation of the Demister^{R}, since packing could be removed from the scrubber without seriously affecting HCl removal. The rapidity of this installation minimized the delay in conducting the trial burn to less than a month after the particulate emissions problem was discovered.

Carbon Tetrachloride DRE

The high organic chloride loading tests were used to check the DREs of CCl_4. As shown in Table 5, these tests demonstrated that 99.99% destruction and removal efficiency (DRE) was achievable. This is adequate to meet RCRA requirements. The low DRE value in the first run was caused by inadequate atomization of the waste liquid at the beginning of the run. Atomization pressure was corrected during the middle of the first run and for subsequent runs. Consequently, DRE improved significantly.

TABLE 5. CARBON TETRACHLORIDE DRE RESULTS FROM HIGH ORGANIC CHLORIDE TEST 1

VOST No.	1	2	3
General Data			
Date	6/18/87	6/18/87	6/19/87
Time	2236-2256	2309-2329	0000-0020
Sampling Data			
Volume Sampled (l)	18.913	19.163	18.385
Meter Temperature (^{o}C)	29.3	31.8	32.3
Barometric Pressure (mm Hg)	735.58	735.58	735.58
Volumetric Flowrate (scfmd)	4366.	4366.	4366.
Analytical Data			
CCl_4 in sample (mg)	0.26	0.009	0.017
Molecular Weight CCl_4	153.82	153.82	153.82
CCl_4 Emissions			
ppm	2.29	0.079	0.156
lb/hr	0.24	0.008	0.016
CCl_4 Feedrate			
lb/hr	190.0	190.0	190.0
CCl_4 DRE			
%	99.87	99.996	99.992

$$\text{ppm} = \frac{(\text{mg } CCl_4 \text{ in sample})\ (1000)\quad (24.45)\quad (760)\quad (T+273)}{(\text{sample volume})\qquad (\text{MW } CCl_4)\quad (P)\quad (298)}$$

$$\text{lb/hr} = \frac{(\text{ppm})\quad (\text{MW } CCl_4)\quad (\text{Volumetric Flow Rate})\quad (60)}{0.0003851}$$

SECTION 6

RCRA/TSCA TRIAL BURN

OBJECTIVE

The objective of the trial burn was to verify that polychlorinated biphenyls (PCBs) and other hazardous organic liquid and solid materials are adequately destroyed by incineration in the EPA Mobile Incineration System (MIS) [13]. The principal organic hazardous constituents (POHCs) were selected to demonstrate destruction of wastes covered by the Toxic Substances Control Act (TSCA) and the Resource Conservation and Recovery Act (RCRA). The selected POHCs ranked high on the EPA's incinerability list developed by Mitre Corporation [14]. Hence, the trial burn was configured to enable future use of the MIS on practically any hazardous organic material, following successful completion of the tests.

POHC SELECTION AND FEED PREPARATION

POHC selection rationale and feed preparation are discussed below.

Hexachloroethane (C_2Cl_6) and PCB-Contaminated Solid Wastes

Hexachloroethane (C_2Cl_6) was the RCRA POHC for the solid feed matrix. Since C_2Cl_6 is very high (No.6) on EPA's incinerability ranking list, the successful incineration of C_2Cl_6 in a solid waste at DREs greater than or equal to 99.99% supports a "RCRA-solids" permit for the Mobile Incinerator and enables use of the incinerator for a variety of solids and sludges. This broad-base RCRA permit should preclude the need for future trial burns when any Appendix VIII constituents below C_2Cl_6 on EPA's incinerability ranking list are to be incinerated by the MIS. The choice of C_2Cl_6 in a solid matrix was made because most of the compounds ranked above C_2Cl_6 are volatile and not likely to be present in significant concentrations in solid wastes that are expected to be fed to the MIS. The C_2Cl_6, a fine-grained solid, was added to the solid/PCB matrix, described below, and to soil to achieve a feed concentration of approximately 1% by weight. Successful operation with PCBs would support a TSCA permit for solids contaminated with PCBs.

Montmorillonite, a chief constituent of several bentonite sources, was used as the solid matrix for PCBs. At an off-site facility, Askarel^{R} oil containing an estimated 50% to 65% PCBs was sprayed onto the montmorillonite and the mixture was placed in polyethylene coated fiber pack drums.

Final solid feed preparation was performed at the site. The mixture of montmorillonite, PCBs, and C_2Cl_6 was blended with soil in a cement mixer, yielding approximately 2% PCBs in the final solid feed. The final blend was poured into drums for feeding into the incinerator.

Carbon Tetrachloride (CCl_4)-Contaminated Organic Liquid Waste

A carbon tetrachloride (CCl_4)-containing waste organic liquid was prepared by blending CCl_4 and Askarel^R with methanol. The liquid blend contained 14 to 28 wt.% CCl_4 and 1 to 2 wt.% PCB, and had a heating value of about 7500 Btu/lb. This liquid was fed through a waste oil nozzle into the rotary kiln. CCl_4 ranks No.4 on the EPA's incinerability ranking list. The purpose of firing CCl_4 liquid during the test was to obtain a flexible RCRA permit that would allow the incineration of waste liquids with low heat values and all Appendix VIII constituents below CCl_4 on the incinerability ranking list. Successful operation with PCBs would support a TSCA permit for liquids contaminated with PCBs.

1,2,4-Trichlorobenzene (TCB)-Contaminated Solid and Liquid Wastes

Since Askarel^R contains approximately 40 wt.% TCB, TCB was selected to be a POHC for both solid and liquid wastes. Solid wastes contained approximately 1.5 wt.% TCB, and liquid wastes contained 0.5 to 1.0 wt.% TCB. TCB was selected as a POHC due to its chemical similarity to many pesticides.

PLANNING

The trial burn [13] was based upon the test plan developed by IT Corporation in December, 1984 [15]. This plan included PCBs and hexachloroethane as the POHCs in the solid matrix and CCl_4 in the liquid matrix. The attempt to execute this plan in 1985 was unsuccessful due to problems with feed control and other mechanical problems. The plan was modified to include the following features:

1. Increase of solids feedrate from nominal 2000 lb/hr to 4000 lb/hr by blending the previously prepared PCB-montmorillonite mixture with soil.

2. Addition of PCBs to the liquid matrix.

3. Addition of TCB as a trial burn POHC.

4. Update of the plan to include recent developments in the stack sampling and analytical methodologies.

5. Update of the plan to cover modifications to the MIS system and development of trial burn heat and material balances to determine operating conditions and parameters required during the testing program.

The planning process for the trial burn centered around the following key steps necessary to complete the testing and to ensure a high probability of project success.

1. Selection of a qualified and experienced subcontractor for sampling and analytical services.

2. Development of Quality Assurance Project Plans (QAPPs) for the operating, sampling, and analytical parameters.

3. Development and execution of a series of shakedown tests designed to evaluate the MIS performance during each aspect of the trial burn program. This included: testing of high organic chlorine loading in the liquid and solid feeds, waste oil nozzle operation, high-BTU solids, low-BTU liquids, montmorillonite feed processing, and others.

4. Development and execution of procedures for feed preparation including: handling, blending, and storage.

5. Revisions to and approval of the revised trial burn plan in order to obtain RCRA and TSCA Trial Burn permits.

Bids were solicited from a large number of stack sampling/analytical laboratories. Based upon a technical and commercial review of the proposals received, Alliance Technologies Corporation of Bedford, MA, was selected as the subcontractor for the stack sampling and analytical services.

Alliance utilized metaTrace Laboratories of Earth City, MO, as a subcontractor for a large portion of the sample analyses, including all delisting analyses. An important aspect of the delisting analysis was the need to turn around the purge water delisting analyses within 24 hr due to the limited storage space for wastewater at the site. Alliance Technologies prepared the QAPP for the sampling and analytical (S&A) portion of the Trial Burn, while Enviresponse prepared the QAPP for the operating and combustion parameter measurement systems. The time period necessary to solicit bids, to select an S&A contractor, and to prepare the initial QAPP was approximately three months. These activities formed the critical path in the trial burn scheduling.

The trial burn plan revision was carried out in conjunction with the selection of the S&A vendor, and was reviewed by the regulatory agencies (RCRA and TSCA) and various EPA support personnel. In addition, this plan was reviewed by two private consultants, Cyril Henke of IT Corporation, coordinator of the previous MIS dioxin trial burn and Joseph Santolieri of Four Nines, Inc. The review of these individuals was considered invaluable based upon their past experiences with the MIS and other trial burns. A TSCA Trial Burn permit was issued by EPA's Office of Toxic Substances and a RCRA Trial Burn permit was issued jointly by EPA Region VII and MDNR.

PROBLEMS AND CHANGES IN SCOPE

The test plan [13] specified a total of three replicate tests with the MIS processing liquid and solid wastes simultaneously. On the first day at the site, the OTS representative stated that two tests were required for each waste matrix and that trash and soil were separate matrices. Trash consisted of the paper and steel drums in which feed was stored, plus wooden pallets and protective clothing. This material would have low levels of contaminants as compared to the feed material. Thus a revision of the test plan was required if processing of PCB-contaminated trash was to be allowed in the final permit.

Since the MIS can not process mixtures of trash and soil at the same rates as soil only, a minimum of four tests were required to obtain a TSCA permit which would allow maximum operating flexibility. The test plan was revised as follows:

- Another test was added.
- The first two tests were to be conducted as orginally planned.
- The third and fourth tests were to be conducted with a mixture of trash and soil at only half of the solids feed rate (2000 lb/hr).

However, equipment problems caused further revisions of the plan and the actual trial burn consisted of six test runs. Three of the test runs were completed (Tests 2, 3, and 5) and the final run was invalidated (Test 6) by the RCRA representative. The three completed tests did not achieve the goal of simultaneously processing both liquid and solid wastes, because Test 2 was performed while processing solid waste only.

As contamination in the system was discovered after Test 5, the sixth trial burn test was postponed until the water system decontamination was completed. Since the discovery of furans in sludge, water and stack gas made Test 5 invalid, the configuration of Test 6 was revised. Test 6 was conducted as a third replicate of the originally planned liquids and solids test. The trial burn ended after Test 6, which was aborted due to repeated interruptions caused by quench system problems and the consumption of all PCB-contaminated solid feed material.

The problems that led to the deviations from the original and revised test plans are discussed below:

Test 1

Test 1 was aborted following blockage of the waste liquid fuel lines. After the test was aborted, an examination of the waste liquid fuel system showed that the screen upstream of the liquid pump had been removed. Prior to Test 2 the following actions were taken to address the blockage:

- The waste oil lines were flushed and liquid was blown back to clear the lines of any debris.
- A flush connection was added close to the waste liquid feed meter.
- A screen was installed upstream of the pump.

Test 2 - Solids Only (No Trash)

Due to an electrical problem with the liquid feed pump, Test 2 was changed to a solids-only run with the concurrence of the Office of Toxic Substances (OTS), Region VII, and the Missouri Department of Natural Resources (MDNR) observers.

The unit operated very smoothly during Test 2. The only operation-related incident occurred during a port change while Modified Method 5 testing was being conducted. Waste feeds were cut on the WEP "outlet gas flow high" interlock but were restored in approximately 30 sec. Hence the incident essentially did not interrupt the test. A check of the interlock revealed that the high outlet gas flow trip was set conservatively low. The trip setting was adjusted prior to Test 3.

The only other incident involved the dioxin sampling train. The condenser on this train broke during the change between the first and second sampling ports. The train was repaired by installing a new condenser and XAD resin.

Test 3 - Solids and Liquids (No Trash)

Prior to this test the continuous CO monitor for the SCC outlet malfunctioned. The regulatory observers permitted the execution of the test because the CO content at the stack was continuously being monitored by the stack sampling crew. The broken instrument was repaired, and a back-up instrument was obtained prior to Test 4.

During the execution of Test 3, two incidents occurred. The first incident was a short in the stack testing equipment, which increased the time required to change ports for stack sampling from a normal 20 min to 40 min. The second incident was a momentary waste feed interruption caused by an operator error. The operator tripped the stack gas alarm while he was working on the broken CO monitor.

Test 4 - Solids, Liquids, and Trash

Test 4 ran smoothly until a mechanical malfunction, a kiln bearing failure, prevented further testing. The incident was serious because it caused generation of furans, which contaminated the process water system. This subsequently caused a release of furans from the stack during a 100-hr period consisting of Test 5 and the operations that followed. As explained below, the release was caused due to a human error and steps have been taken to prevent any recurrence in future operations. A noncompliance report was filed immediately with MDNR as soon as the stack release was detected.

Furans Release

The furans release occurred in the following manner. The kiln rotation was stopped due to the kiln bearing failure. After the kiln rotation was stopped, the operators manually shut down the entire system. This action stopped the kiln burners, the SCC burners, and the ID fan. The ID fan was quickly restarted because of the puffing from the kiln but the SCC burners were not restarted. Failure to restart the SCC burners was a critical error because this created a rapid drop in the SCC temperature. This temperature drop caused generation of furans due to incomplete combustion of PCBs which continued to volatilize from the solid waste remaining in the kiln. Consequently, these furans contaminated the process water system as shown by their presence in both the process water sample taken prior to Test 5 and the water samples taken during Test 5. Some of these furans then were released from the stack during Test 5.

The contamination of the process water system was not discovered until after Test 5 had been completed the following day. At this point, further trial burn testing was postponed and normal operations were continued until it was pointed out that they should be stopped in order to decontaminate the process water system.

The primary lesson learned from this experience is that should the kiln rotation be stopped with material in the kiln, the SCC burners must continue to operate. Operators have been instructed to keep the SCC burners on whenever the kiln rotation is stopped. If the SCC burners should trip, they should be relit following proper procedures including an air purge. A second lesson learned from this experience is that if ever there is any indication of contamination in process water, the system operation should be terminated because of the potential for the release of contaminants from the stack. The process water should be analyzed to determine if contamination has occurred, and then be completely decontaminated if necessary.

Risk Analysis

Since a release of furans is potentially harmful to the surrounding population, a risk analysis [5] was conducted to determine the impact of the furans release. The risk analysis was conducted using state-of-the-art methodology and in accordance with EPA procedures. [See Appendix B for the complete Risk Analysis.] In addition, the risk analysis always assumed a "worst case scenario". The results showed that the incident was minor. There was no additional risk to the public resulting from the incident.

Kiln Bearing Failure

The kiln is held in radial position by four rollers (two driven, two idlers). Each radial roller is supported by two pillow block-style bearings which are retained and locked on the roller shafts with Allen-style set screws. The axial position of the kiln is maintained by a single thrust roller (made of soft steel) operating against gravity and the thrust ring. Gravity acts to move the tilted kiln in the down slope direction.

The bearing failure occurred as follows: Over a long period of time (a few years) the harder thrust ring had produced a groove (approximately 1/4-in deep) in the axial roller. Several days after maintenance was performed on the pillow block bearing at the head (upper end) of the kiln, two bearing inner races held by the Allen set screws became loose and worked their way out of the bearing. This allowed the kiln rotating cylinder to drop approximately 3/8 in. Because the thrust ring had worn a groove in the axial thrust roller, an extreme tilting force was applied to the thrust roller as a result of the movement. This in turn caused a total failure of the two shaft bearings of the thrust roller. Since the failure was recognized quickly and kiln rotation was immediately stopped, no other physical damage occurred. The bearing failures were corrected by ensuring that the Allen set screws on the pillow block bearings were properly fastened and then locked.

Test 5 - Solids, Liquids, and Trash

Although the plan called for 315 lb/hr waste liquid flow rate, it was only 132 lb/hr at the start of the test run due to problems with the liquid waste pump. Since this flow was adequate to prove DREs, the Modified Method 5 (MM5) and VOST sampling were started at this lower flowrate. However, as the test proceeded, the flowrate decayed to about 100 lb/hr. At this point, as discussed below, MM5 sampling was stopped during a stack sampling port change to allow installation of a new pump. The liquid waste flowrate then was restored to 270 lb/hr. Examination of the poorly operating first pump showed that this gear pump had developed excessive clearances due to wear. To avoid this problem in the future, the gear pump was replaced by a diaphragm pump prior to Test 6.

There were five feed interruptions during the test but only one interruption occurred while stack sampling was taking place. The waste feeds were cut for about one minute following a WEP outlet gas flow high alarm. Two of the interruptions were related to maintenance.

The remaining two interruptions occurred during port changes. A failure of the weigh cell hopper gate caused an eleven minute interruption, and consecutive trips on abnormal stack gas caused another four-minute interruption.

Test 6 - Solids and Liquids

As mentioned earlier, this test was to be conducted with 2000 lb/hr of solids including significant amounts of trash. Since Test 5 showed furans in the sludge, water and stack gas, Test 6 was reconfigured to be the third replicate as per the original trial burn plan.

Although the test ran long enough to collect stack samples for DRE and products of incomplete combustion (PIC) analyses, it was declared invalid due to repeated feed interruptions mainly caused by low quench circulation flow. The low quench flows were caused by a recirculation pump, which periodically cavitated due to low net positive suction head (NPSH). The pump cavitation was caused by an excessive chlorinated waste feedrate as follows: Incineration of chlorinated wastes generates hydrogen chloride (HCl) as a product. The quench water is treated with caustic solution. Reaction between HCl in the combustion gases and sodium hydroxide (NaOH) in the quench sump produces effervescence. The amount of effervescence increases to violent levels as HCl flowrate increases. The violent effervescence reduces available NPSH, which causes cavitation at the very high HCl loads.

A long 51-min interruption occurred when the waste liquid flowmeter plugged. As the meter was being unplugged, it was damaged and it stopped working. The liquid level in the waste tank was taken and sampling was resumed.

There were five minor interruptions due to trips on low oxygen. These were traced to a partially plugged sampling probe after the test.

The other feed interruptions were caused by low quench flow trips. The low quench flow trip shuts down all burners and feed. These are restarted immediately but the system experiences rapid transitions such as rapid decreases in temperature, which can cause further feed interruptions.

OPERATING PARAMETERS

The incinerator operating conditions used during the Trial Burn were similiar to those that are used during the normal processing of dioxin contaminated materials. These operating conditions were demonstrated during the 1985 dioxin trial burn [11] with the exception of the solid feedrate. An increase in solid feedrate to 4000 lb/hr was demonstrated in June 1987, as specified in the operating permit [10].

The incinerator was operated in the following manner. Waste solids and liquids were fed to the rotary kiln, which was controlled at 1570°F. At the typical feedrate of 4000 lb/hr and a kiln revolution rate of 1.6 rpm, the solids were retained in the kiln for approximately 20 min as they were thermally decontaminated. Processed solids then were discharged into drums. Liquid feed rates ranged between 120 lb/hr to 360 lb/hr in Tests 3 and 5 but no liquids were fed during Test 2. The gases generated in the rotary kiln passed through a cyclone to remove fine particulate and entered the SCC. In the SCC, the gases were heated up to 2120°F and then retained for about 2.5 sec to complete the waste destruction process. Sufficient excess oxygen is provided in the kiln and sufficient excess air is provided in the SCC to ensure complete combustion. Excess oxygen (O_2) was about 7.5%, and carbon dioxide (CO_2) was about 15% at the exit of the SCC. Carbon monoxide (CO) emissions were less than 25 ppm showing that combustion was essentially complete. The SCC exit flue gases containing approximately 200 lb/hr of HCl were cooled in the quench elbow, particulates were removed in the WEP, and final acid gas removal occurred in the MX scrubber. Average process conditions for each completed test run are shown in Table 6 for Test numbers 2, 3, and 5 respectively.

TEST RESULTS

In order to pass the trial burn, the MIS had to

TABLE 6. TRIAL BURN AVERAGE PROCESS OPERATING CONDITIONS

		Test 2	Test 3	Test 5	Test 6
Date (1987)		7/29-7/30	7/30-7/31	8/1/-8/2	8/31-9/1
Time (Begin-end)		21:00-06:01	23:00-06:38	23:18-07:41	23:00-08:15
Test Description		Solid Wastes	Solid & Liquid Wastes	Solid & Liquid Wastes & Trash	Solid & Liquid Wastes
GENERAL:					
Total Thermal Load	(10^6BTU/hr)	8.41	10.47	9.47	10.08
Total Oxidation Flow(a)	(scfm)	1849	1899	1923	1750
Combustion Efficiency(b)	(%)	99.981	99.986	99.986	99.99
KILN:					
Combustion Temperature	(°F)	1580	1587	1580	1591
Solid Waste Feed Rate	(lb/hr)	4045	3900	3810	3690
Liquid Waste Feed Rate	(lb/hr)	NA	355	145.2	289
Fuel to Oxygen Burner	(lb/hr)	161.8	51.7	87.9	84.5
Oxygen Flow Rate	(scfh)	8180	7050	6680	5760
Vacuum (Draft)	(in w.c.)	0.26	0.27	0.28	0.24
Oxygen	(%)	7.84	8.22	8.16	7.98
SCC:					
Combustion Temperature	(°F)	2118	2112	2120	2120
Combustion Air Flow	(scfm)	1182	1148	1170	1175
Fuel Flow	(lb/hr)	40.55	39.58	39.88	39.91
Vacuum (Draft)	(in w.c.)	2.61	2.93	2.74	2.66
Quench Water Recirc. Flow	(gpm)	49.0	49.0	49.0	49.0
Quench Water pH		9.7	9.41	8.48	8.58
Gas Exit Temperature	(°F)	171.5	171.9	184.8	171.6
Oxygen GC	(%)	7.56	7.25	7.23	11.6
Oxygen Polarographic	(%)	6.57	6.46	6.26	8.3
Carbon Dioxide GC	(%)	15.31	15.03	14.76	9.65
Carbon Monoxide GC	(ppm)	0.64	0.48	10.5	5.0
Total Hydrocarbons GC	(ppm)	1.00	2.82	14.1	1.7
Nitrogen Dioxide	(ppm)	138.3	54.6	96.4	157.2
SCC Residence Time(c)	(sec)	2.64	2.53	2.65	2.35
WEP:					
AC Voltage	(V)	138.8	134.3	138.9	140.0
AC Amperes	(a)	25.0	25.0	25.0	25.0
DC Voltage	(KV)	12.0	11.97	12.34	12.36
DC Milliamperes	(ma)	60.0	60.0	60.00	60.00
Fluegas	(ACFM)	5025	5374	5420	5050

(continued)

TABLE 6. (continued)

		Test 2	Test 3	Test 5	Test 6
Date (1987)		7/29-7/30	7/30-7/31	8/1/-8/2	8/31-9/1
Time (Begin-end)		21:00-06:01	23:00-06:38	23:18-07:41	23:00-08:15
Test Description		Solid Wastes	Solid & Liquid Wastes	Solid & Liquid Wastes & Trash	Solid & Liquid Wastes
MX SCRUBBER:					
Recirc. Water Flow	(gpm)	110.9	110	110.0	110
Water Temperature	(°F)	177.0	NA	176.1	176.1
Scrubber Water pH		8.45	7.98	8.51	8.23
Scrubber Purge Water	(gpm)	10.8	9.19	10.48	10.81
ID FAN:					
Vacuum (Draft)	(in w.c.)	11.81	13.87	12.94	12.63
STACK:					
Oxygen	(%)(d)	9.1	9.7	9.6	10.8
Carbon Monoxide	(ppm)(d)	22.5	17.2	17.3	9.6
Oxygen Orsat	(%)	10.0	9.0	9.3	8.7
Carbon Dioxide Orsat	(%)	12.4	12.6	12.4	13.9
Total Hydrocarbons	(ppm)	-	-	-	-
Nitrogen Dioxide	(ppm)	-	-	-	-

(a) (Oxygen flow and air flow to rotary kiln) + air flow to SCC

(b) Combustion effiency = (1 - % carbon monoxide/% carbon dioxide) x 100
Combustion efficiency was calculated for the stack emmisions.

(c) Calculated from material balance

(d) From continuous emission monitor

demonstrate performance which met the regulatory requirements. The chief performance criteria were the destruction and removal efficiencies (DRE) for POHCs. Other important performance criteria include: those for combustion efficiency, acid gas removal efficiency, particulate emissions, products of incomplete combustion (PICs), and effluent quality. The performance of the MIS relative to these criteria are discussed below.

DRE Performance

The performance of the incinerator during the Trial Burn was accurately determined by monitoring all feed and effluent streams. The main performance criteria were the destruction and removal efficiencies (DRE) for:

1. PCBs, which are regulated by the Toxic Substances Control Act (TSCA). Required DRE >99.9999%.

2. CCl_4, which is regulated by the Resource Conservation Recovery Act (RCRA). This was the surrogate compound for volatile organic hazardous wastes. Required DRE >99.99%.

3. C_2Cl_6, which is regulated by RCRA. This was the surrogate compound for solid hazardous wastes. Required DRE >99.99%.

4. TCB, which is regulated by RCRA. This was the surrogate compound for pesticides. Required DRE >99.99%.

As shown in Table 7 the incinerator demonstrated excellent performance in destroying these compounds. The DRE criteria for the PCBs was exceeded by two orders of magnitude and the DREs for the RCRA compounds exceeded the criteria by one to two orders of magnitude as shown below:

	Lowest DRE	Highest DRE
PCBs	99.9999965%	99.9999996%
CCl_4	99.99877%	99.9996%
TCB	99.99968%	99.99996%
C_2Cl_6	99.9981%	99.999984%

As mentioned previously, Test 6 was declared invalid due to several interruptions during the test. This data, however, is included in Table 7 for information only. The DRE calculations are presented in Appendix C.

Combustion efficiency also exceeded 99.9% as required by both TSCA and RCRA. This is shown in Table 6.

TABLE 7. DESTRUCTION AND REMOVAL EFFICIENCY (DRE) FOR THE TSCA/RCRA TRIAL BURN

	Test 2	Test 3	Test 5	Test 6
Polychlorinated Biphenyls (PCBs)	99.9999996	99.9999995	99.9999965	99.999988
Carbon Tetrachloride (CCl_4)				
Low VOST(a)	NA	99.99968	99.99916	99.99912
High VOST(a)	NA	99.99958	99.99869	99.99942
1,2,4-Trichlorobenzene (TCB)	99.99991	99.99968	99.99996	99.99998
Hexachloroethane (HXE)	99.999844	99.9981	99.999976	99.999996

(a) Average of 3 VOST pairs per run.
All DREs given in units of percent destroyed.

Acid Gas Removal

The Mobile Incineration System (MIS) provides an exceptional amount of hydrogen chloride (HCl) removal. The system removes over 99.9% HCl; the regulatory requirement is 99% removal. HCl emission rates were only 0.26 g/min with HCl inputs (based upon the ultimate analysis of the feed) as high as 1,500 g/min. The HCl emissions results are summarized in Table 8.

Particulate Emissions

Particulate emissions were within the 0.08 gr/dscf (corrected to 12% CO_2) regulatory limit for Test 2 (0.064 gr/dscf) and Test 3 (0.066 gr/dscf). However, the 0.084 gr/dscf emission rate for Test 5 slightly exceeded the regulatory limit. The violation occurred due to very high concentrations of total dissolved solids (TDS), over 49,000 ppm, in the process water. This is illustrated in Figure 13, which shows that particulate emissions were proportional to TDS during the Trial Burn testing. The results of these particulate emissions and corresponding TDS also are given in Table 9. These high concentrations typically would not be encountered because much lower chlorine loadings are processed during normal operations.

The baseline effect of TDS on the particulate emissions has been determined through a test in which no soil was fed and water TDS was measured as 50,000 ppm. A particulate emission of 0.028 gr/dscf was measured in this test. Analysis of the filter showed that the particulate matter collected during this test was mainly sodium chloride plus sodium hydroxide as shown in Table 10. Table 10 shows that most of the particulate matter collected on the filters for Test 3 and Test 5 also consisted mainly of sodium chloride and sodium hydroxide. Sodium chloride and sodium hydroxide are the chief components of the TDS in the process water.

Thus it would be logical to deduce that if the TDS of process water was maintained at reasonable levels the particulate emission would be well below the regulatory limits. Figure 13 shows that TDS levels below 20,000 ppm would provide an adequate margin for the particulate emissions.

Products of Incomplete Combustion (PICS)

As shown in Table 11, dioxins and furans (TCDD & TCDF) were not found in significant quantities in Tests 2 and 3. The concentration levels of all isomers expressed as 2, 3, 7, 8-TCDD equivalents were less than 1 ng/l for Test 2 and less than 10 ng/l for Test 3. However, in Test 5, significant levels of furans were detected in the stack gas, sludge, and

TABLE 8. GASEOUS HCl EMISSIONS SUMMARY

Test Description:	Trial Burn Test 2	Trial Burn Test 3	Trial Burn Test 5
Date (1987)	7/29-30	7/30-31	8/1-2
Sampling Times			
Start	04:05	04:46	05:46
Stop	06:01	06:38	07:41
Stack Temp. (°F)	173	170	172
Flow Rate (dscfm)	2281	2742	2519
Total Chlorine Input as HCl (g/min)	854	1261	1160
Chloride Detected (ug)	4064	3400	1946
Sample Volume (dscf)	37.040	42.903	42.920
Concentration as HCl (ug/dscf)	112.8	81.5	46.6
Emission Rate(a) as HCl (g/min)	0.257	0.223	0.117
(lb/hr)	0.034	0.030	0.016
HCl Removal(b) Efficiency (%)	99.97	99.98	99.99

(a) The operating permit required emission rates less than 4 lb/hr or a HCl removal efficiency of 99%.

(b) Removal Efficiency = (HCl input - HCl output)/HCl input x 100

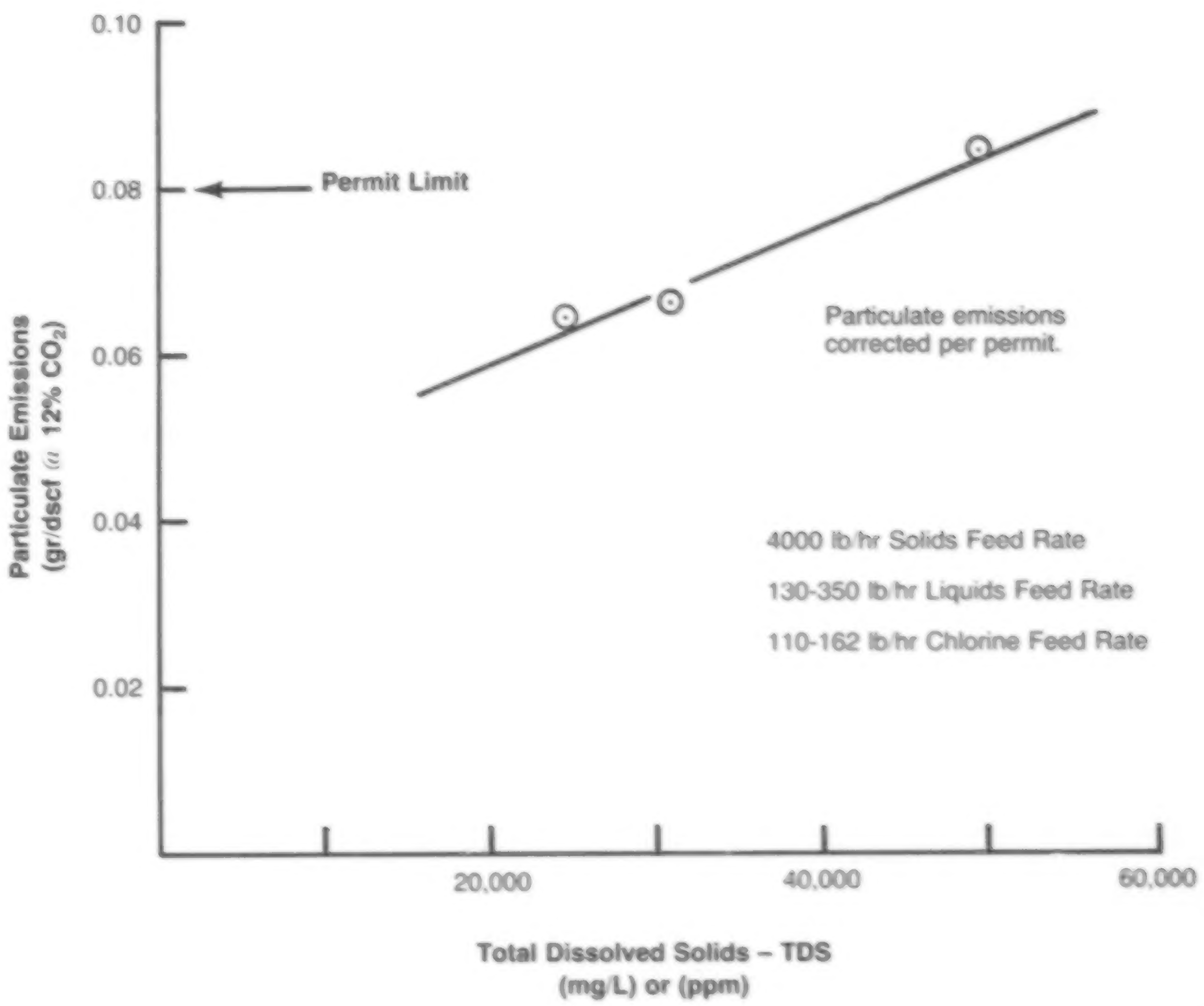


Figure 13. Effect of TDS on particulate emissions.

TABLE 9. PARTICULATE SAMPLING PARAMETERS AND EMISSIONS SUMMARY - TRIAL BURN RUNS

Test Description:	Trial Burn Test 2	Trial Burn Test 3	Trial Burn Test 5	Baseline
Date (1987)	7/29-30	7/30-31	8/1-2	9/1
Sampling Times (Begin-End)	04:05-06:01	04:46-06:38	05:46-07:41	20:24-23:30
Stack Gas Data				
Moisture (%) measured	55.8	55.2	54.6	42.3
Moisture (%) calculated	45.8	42.9	45.1	41.3
Dry mole fraction (100 - %M)	0.5418	0.5705	0.5486	0.5874
CO_2 (% dry)	12.4	12.4	12.5	8.0
O_2 (% dry)	10.0	9.4	9.0	13.0
N_2 (% dry)	77.6	78.2	78.5	79.0
Avg. Stack Temp. (°F)	173.0	170.2	172.2	170.6
Stack Gas Velocity (afpm)	1323.1	1503.1	1446.3	1254.1
Stack Flow Rate (dscfm)	2280.5	2741.6	2518.6	2476.1
Stack Flow Rate (wscfm)	5292.2	6012.6	5785.4	5016.2
Particulate Emissions				
Actual (gr/dscf)	0.0665	0.0679	0.0878	0.0187
Actual (gr/ascf)	0.0286	0.0309	0.0382	0.0093
Corrected @ 12% CO_2(gr/dscf)	0.0643	0.0657	0.0843	0.0281
Corrected per permit(gr/dscf)	0.0653	0.0662	0.0846	NA
Pounds/hour	1.2989	1.5947	1.8962	0.3977
Total Dissolved Solids				
Scrubber Water Prior (mg/L)	24365	30494	49437	50000
Scrubber Water Composite	NA	37712	45742	NA
Organic Chloride Feed Rate				
Feed Rate (Lb/hr) by analysis	110	162	149	NA
Feed Rate (Lb/hr)(a)	168	208	196	0

(a) Based upon weight added to feeds (not used in acid removal calculations.)

TABLE 10. PARTICULATE FILTER ANALYSES

Test No. Units	3 (ug/filter)	5 (ug/filter)	Baseline (ug/filter)
Aluminum)	309	244	214
Carbon	<400	556	<400
Chlorine	57600	146000 (a)	14600
Chromium	90	166	28
Iron	7550	7910	153
Silicon	488	492	468
Sodium	43920	73760	488
Total	115025	228458	40992
As Sodium Chloride	94925	219760	24061
As Sodium Hydroxide (Excess Caustic)	11668	0	16968

(a) Chlorine reported seems high based upon the other analyses.

TABLE 11. DIOXIN/FURAN LEVELS IN
STACK GAS SAMPLES

Test No.	2		3		5		6	
Units	(ng)	(ug/m^3)	(ng)	(ug/m^3)	(ng)	(ug/m^3)	(ng)	(ug/m^3)
Isomer Groups								
Total Tetra-CDD	<0.9	<0.0004	<1.4	<0.0005	11	0.0038	<15	<0.0066
2,3,7,8 Tetra-CDD	<1.0	<0.0004	<1.0	<0.0003	<1.0	<0.0003	<1.0	<0.0004
Totat Tetra-CDF	0.6	0.0002	1.8	0.0007	17000(a)	5.8754	510	0.2249
2,3,7,8 Tetra-CDF	<1.0	<0.0004	<1.0	>0.0004	850	0.2938	<1.0	<0.0004
Total Penta-CDD	<2.1	<0.0008	<5.0	<0.0019	14	0.0048	<310	<0.1367
Total Penta-CDF	<1.5	<0.0006	130	0.0495	25000(a)	8.6403	<84	<0.0370
Total Hexa-CDD	<2.7	<0.0011	24	0.0091	20	0.0069	<1100(a)	<0.4851
Total Hexa-CDF	1.3	0.0005	300	0.1141	4800(a)	1.6589	<590	<0.2602
Total Hepta-CDD	<0.7	<0.0003	45	0.0171	<2.7	<0.0009	<230	<0.1014
Total Hepta-CDF	<2.0	0.0008	130	0.0495	330	0.1141	<5.8	<0.0026
Total Octa-CDD	6.3	0.0025	27	0.0103	<7.4	<0.0026	<0.9	<0.0004
Total Octa-CDF	<1.3	<0.0005	38	0.0145	<11	<.0038	<0.6	<0.0003

(a) Estimated Value - above linear range of calibration curve.

scrubber water. The furans were not generated during Test 5. They were generated due to the failure to reignite the SCC burners following the incident that stopped Test 4. Data presented in Table 11 show that the furan species in the process water (scrubber water purge) sampled prior to Test 5 were nearly identical to those in water sampled after Test 5. Note that the highest concentrations of furans were in the sludge samples, thus indicating that the furans were associated with suspended solids. In examining Table 12, it should be noted that water with contaminated suspended solids yields significant variability among samples. This is illustrated by the variability before and after Test 5 and also variability between aliquots of the same sample, as shown in the Test 5 water data. Process water samples from Tests 2 and 3 had no measurable concentration of dioxins or furans. Based on the data from the previous successful PCB trial burn in 1983, Tests 2 and 3 of the 1987 trial burn, and the similiarity between those tests and the operating conditions of the incinerator during Test 5, it can be concluded that no measurable dioxin or furan PICs resulted from Test 5 and that the stack contamination arose solely as a result of the contaminated process water.

Volatile organic PICs were produced in very small quantities for all test runs as shown in Tables 13 and 14. Based upon both the volatile organics and the dioxins and furans results, the trial burn demonstrated that the MIS can successfully destroy hazardous organic compounds without generating significant quantities of PICs. The VOST sampling methods are discussed starting on page 76 of this report.

Stack Gas Monitoring

The combustion gases were continuously monitored for NO_x, CO, THC, and O_2 by two continuous emissions monitor (CEM) systems. The first system was the permanent analyzer system attached to MIS. This sampled gases from the exit of the SCC and also monitored CO_2 continuously. The second system was brought in to provide a check and back up of the MIS CEM system. This system sampled gases from the stack. Integrated Orsat samples for O_2, CO_2, and CO also were taken during the tests.

The monitoring results, presented in Table 6, were within expected performance norms. As shown by the carbon monoxide and total unburned hydrocarbons results, combustion was very clean and essentially complete. Excess oxygen concentration was higher in the stack than at the exit of the SCC. Carbon dioxide concentration was lower in the stack than at the exit of the SCC. This behavior is expected and is caused by air leakage into the unit downstream of the SCC. NO_x emissions also were reasonable, averaging between 54 and 138 vppm during the three tests.

TABLE 12. DIOXIN AND FURAN LEVELS IN THE SEPARATOR SLUDGE AND PROCESS WATER

Test No.	2 Sludge	3 Sludge	5 Sludge	5 Water	Prior to 5 Water
Units	(ng/L) (ppt)	(ng/L) (ppt)	(ng/L) (ppt)	(ng/L) (ppt)	(ng/L) (ppt)
TCDD	ND	ND	ND	ND	ND
TCDF	4.3	ND	82,000 (a)	180/270	260
2,3,7,8 TCDF	ND	-	ND	90	-
PeCDD	ND	ND	ND	ND	ND
PeCDf	8.5	ND	150,000 (a)	350/310	120
HxCDD	ND	4.7	250	ND	ND
HxCDF	ND	ND	103,000	140/100	50
HpCDD	ND	ND	103	ND	ND
HpCDF	ND	ND	52,000 (a)	17/20	17
OCDD	16	13	ND	ND	ND
OCDF	ND	ND	ND	2.4/ND	ND

Test No. 5 Water was analyzed twice

Test No. 5 A water sample was taken prior to introducing feed to the unit to establish base conditions.

(a) Estimated Value - above linear range of calibration curve.

TABLE 13. RESULTS OF LOW VOST ANALYSES FOR ORGANIC PICs

Test No.	2			3			5			6	
Sample Units (ug/m^3)	1	2	3	1	2	3	1	2	3	1	2
Benzene	33.1	16.1	18.7	9.5	14.7	19.7	11.0	ND	ND	17.3	11.3
Carbon Tetrachloride (a)	14.6	7.7	10.3	36.6	11.7	14.9	42.3	25.3	20.0	64.0	31.6
Chlorobenzene	3.3	ND	ND	ND	3.0	ND	ND	ND	ND	ND	ND
Chloroform	64.9	69.6	72.8	27.1	32.0	25.1	31.3	ND	22.3	46.7	24.0
1,1 Dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2 Dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Methylene chloride	ND	ND	152.6	264.2	ND	129.8	305.2	363.3	112.0	2303.2	1072.9
Tetrachloroethylene	22.5	6.4	13.5	6.1	11.7	8.8	7.0	ND	ND	14.3	5.3
Toluene	27.8	16.1	12.9	13.6	11.2	16.3	15.6	ND	ND	23.3	15.0
Trichloroethylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	9.0	ND

(a) Carbon Tetrachloride is a PIC for test 2 only. No liquid waste fed in test 2.

Detection limit for all compounds = 5 ng.

TABLE 14. RESULTS OF HIGH VOST ANALYSES FOR ORGANIC PICs

Test No.	2		3			5			6			
Sample Units (ug/m^3)	1	2	1	2	3	1	2	3	1	2	3	4
Benzene	6.7	2.7	10.7	11.7	12.9	7.6	10.1	5.7	6.6	4.3	5.9	2.8
Carbon Tetrachloride (a)	35.9	67.3	27.0	13.4	20.0	34.6	52.6	50.5	33.3	24.9	44.7	27.2
Chlorobenzene	1.3	ND	2.1	2.2	2.4	1.8	1.9	2.0	2.2	2.2	1.8	1.6
Chloroform	12.5	1.0	18.0	16.7	23.7	13.2	12.7	10.7	8.1	7.8	5.8	5.7
1,1 Dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2 Dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Methylene chloride	43.5	36.6	68.2	180.0	38.7	56.9	57.1	58.2	52.2	39.7	34.8	34.7
Tetrachloroethylene	72.0	21.3	17.4	17.9	8.3	7.0	5.1	4.8	3.9	4.0	3.3	2.7
Toluene	3.4	8.3	5.8	5.9	1.8	7.1	3.7	3.2	4.0	5.6	2.9	1.9
Trichloroethylene	ND	ND	0.3	0.3	1.2	0.3	0.5	1.8	0.4	2.0	0.4	0.4

(a) Carbon Tetrachloride is a PIC for test 2 only. No liquid waste fed in test 2.

Detection limit for all compounds = 5 ng.

Effluent Stream Analyses

Effluent streams consist of kiln and cyclone ash, scrubber purge water, and separator sludge. The separator sludge is the particulate matter that has been removed from the flue gases by the quench water, WEP and the MX scrubber. This particulate matter then is separated from the process water by settling and filtration. The effluent streams from the trial burn were covered by a delisting agreement under which these materials would be classified as nonhazardous wastes. These streams were required to be analyzed for volatile organics, semivolatile organics, PCBs (as Aroclors), PCDD/PCDFs, and EP Toxicity (metals). The delisting criteria and the effluent analyses are presented in Tables D-1 through D-14 in Appendix D.

The kiln ash and cyclone ash from all three tests contained no detectable levels of the delisting organic compounds, as shown in Tables D-1 through d-6, with the exception of Test 5 cyclone ash. The Test 5 cyclone ash contained trace quantities of penta-CDD, hepta-CDF, and octa-CDD, none of which exceeded the delisting criteria. In addition, the EP Toxicity analysis indicated acceptable levels of all metals, as shown in Table D-14 in Appendix D. All of the kiln ash and cyclone ash from Tests 2, 3, and 5 passed delisting requirements and were disposed of as nonhazardous wastes.

The scrubber purge water and separator sludge analyses paralleled the stack gas analyses as illustrated in Tables D-7 to D-13 in Appendix D. No organic compounds were detected in the scrubber purge water for Tests 2 and 3. The EP Toxicity analysis indicated acceptable levels of all metals for the scrubber purge water and separator sludge for all test runs. Only trace quantities of furans, close to the analytical detection limits and below the delisting criteria, were detected in the separator sludge for Tests 2 and 3. However, both the scrubber purge water and the separator sludge for Test 5 contained significant quantities of furans. These streams also contained small quantities of PCBs.

The scrubber purge water and separator sludge from Tests 2 and 3 passed all delisting requirements and were disposed of as nonhazardous waste. The Test 5 scrubber purge water and separator sludge were treated to furan levels below the delisting criteria prior to disposal.

PERMITS OBTAINED AS A RESULT OF THE TRIAL BURN

As a result of the Trial Burn, the MIS has been technically qualified for processing canceled pesticides. However, due to the fact that the particulate emissions in

Test 5 slightly exceeded the regulatory limit (0.084 gr/dscf versus 0.08 gr/dscf), and the fact that furans were detected in the stack gas as a result of the aborted Test 4, a full operating TSCA permit was not granted by OTS. Although these data prevented the incinerator from receiving full TSCA approval, the overall results of the Trial Burn showed unequivocally that the Mobile Incineration System destroys PCBs to six 9's or better, while maintaining all regulatory requirements.

SAMPLING AND MONITORING PROCEDURES

This section provides a brief overview of field sampling and associated protocols and procedures. A complete description of the procedures used is provided in the Quality Assurance Project Plan (QAPP) [16,17] previously submitted and revised.

Sampling Locations and Procedures

The locations where solid, liquid, and gaseous samples were collected from the Incineration System are shown in Figure 14. All of the materials supplied to the incineration and air pollution control processes, including auxiliary fuel, liquid and solid waste feeds, makeup water and alkaline neutralizing solution were sampled at locations 1, 2, 3, 5, and 7. Samples of process solids (ash and sludge) and liquid (purge water) effluents were collected at locations 4, 6, and 13. POHC, HCl, and particulate emission samples were collected from the stack gases at locations 8 and 9. The composition of the combustion gases was continuously monitored at the exit duct from the SCC (locations 10 and 11) and at the stack (location 12). Additional details regarding each of the process sampling locations are discussed below.

Auxiliary Fuel (1) --

Fuel oil is fed from a large storage tank. Grab samples were collected from a supply line tap at the beginning, middle, and end of each run and composited for the run.

Organic Liquid Feed (2) --

The test mixtures were prepared in and fed from a 1000 gal mix tank. The mix tank includes an agitator, recirculation system, sample collection loop, and feed pump. Grab samples were collected at 15-min intervals and composited for the run.

Solids Feed (3) --

The solid feed matrix consisted of montmorillonite with adsorbed Askarel^R (containing approximately 60 wt % PCBs), hexachloroethane, and soil. The PCB/montmorillonite mixture had been previously prepared and was placed in sealed fiber drums along with a bag containing a pre-weighed quantity of hexachloroethane.

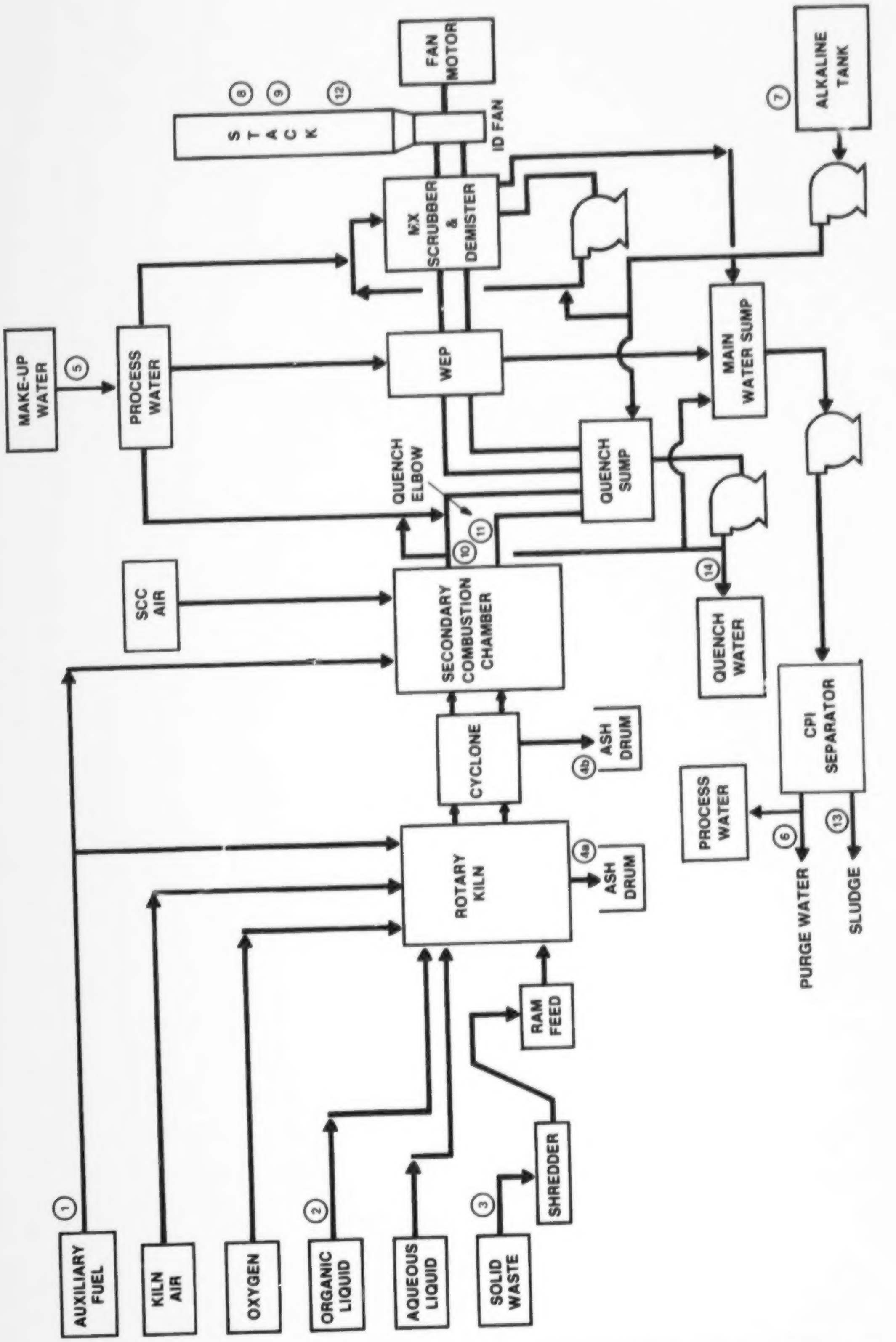

AUXILIARY FUEL
KILN AIR
OXYGEN
ORGANIC LIQUID
AQUEOUS LIQUID
SOLID WASTE
SHREDDER
RAM FEED
ROTARY KILN
ASH DRUM
CYCLONE
ASH DRUM
SECONDARY COMBUSTION CHAMBER
SCC AIR
QUENCH ELBOW
QUENCH SUMP
QUENCH WATER
MAKE-UP WATER
PROCESS WATER
WEP
MAIN WATER SUMP
MX SCRUBBER & DEMISTER
ID FAN
FAN MOTOR
STACK
ALKALINE TANK
CPI SEPARATOR
PROCESS WATER
PURGE WATER
SLUDGE
①
②
③
4a
4b
⑤
⑥
⑦
⑧
⑨
⑩
⑪
⑫
⑬
⑭

Figure 14. Sampling locations for trial burn testing.

In order to prepare a sufficient quantity of feed material at the nominal solids feedrate of 4000 lb/hr, the PCB/montmorillonite material was mixed with soil in a cement mixer.

The solid feed was prepared by adding the following to the cement mixer to produce a batch: twenty-two drums of the PCB/montmorillonite (approximately 4300 pounds, with approximately six gallons of water added per drum for dust control and adjustment of feed moisture content); five 55-gal drums of clean soil (approximately 3150 pounds), and 149 pounds of C_2Cl_6. The batch then was mixed for approximately 30-min, and then returned to the fiber drums. Four batches of feed material were required for each trial burn run. The incinerator was fed by dumping the contents of each drum into the shredder.

This feed preparation provided a more homogeneous mixture than the mixing soil and montmorillonite in the shredder as originally proposed in the trial burn plan. This was confirmed by tests conducted during the shakedown operations which indicated that the montmorillonite would immediately flow through the shredder preventing sufficient time for mixing with soil in the shredder.

Kiln (4a) and Cyclone Ash (4b) --

Bulk ash was collected separately from the kiln and cyclone in 55-gal metal drums, which were covered, and allowed to cool. A spoon was used to collect a grab sample from each container. The samples collected during each replicate test run were composited. The kiln ash and cyclone ash were collected, composited, and analyzed separately.

Makeup Water (5) --

Grab samples were collected from a supply line tap at the beginning, middle, and end of the run and composited.

Scrubber Blowdown (Purge Water) (6) --

Samples were taken from a tap in a discharge line prior to the water entering the wastewater storage tanks. Samples were taken at 15-min intervals, beginning after test start and ending with test completion. Samples then were composited. Before starting the solid and liquid feeds, a sample was collected to provide a blank sample for each sampling run. This sample was taken to establish background contaminant levels in the water system prior to each test.

Alkaline Solution (7) --

One sample was taken from the storage tank pump suction line per test run.

Combustion Gas (10,11) --

Two gas sample streams were extracted from the SCC exit duct at locations 10 and 11 as shown in Figure 13. Each gas stream was filtered, cooled, and dried as it exited the probe before it was transported to the analytical instruments located nearby in a mobile trailer. Gas samples from location 10 were analyzed for NO_x by chemiluminescent detector and for O_2, CO_2, and CO by a gas chromatograph (GC). Gas samples from location 11 were continuously monitored for CO by nondispersive infrared (NDIR) and for O_2 by polarographic detector.

Stack Gas (12) --

Continuous emission monitoring (CEM) of the stack gases was done by the Alliance Technology Corporation subcontractors (Emission Testing Services, Inc., of Baton Rouge, LA for Tests 2, 3, and 5; and TRC-ECI of E. Hartford, CT for Test 6). Due to the stack configuration, the sample gas was extracted from the stack through the MIS probe and sample conditioning system. Upon exiting the on-site conditioning system, the gas passed through a heated line to the CEM trailer. As a precautionary measure, the gas stream then was passed through the CEM's normal conditioning system. The gas stream then was diverted to the various analyzers through a manifold system. The analyzers and associated QA procedures are described in the QAPP. During Tests 1 through 5, a CO_2 analyzer was not available, and thus integrated bag samples were collected and analyzed by the Orsat method.

CPI Separator Sludge (13) --

Sludge that was accumulated in the separator was drained into a holding basin at the end of each test run. The solid material was allowed to settle and a composite sample was taken by removing aliquots from each section of the basin. This basin was emptied and cleaned prior to each trial burn test.

Quench Water (14) --

In addition to the wastewater, samples were taken of the quench recirculation water. This sample matrix was added after the final revision to the trial burn plan and QAPP. This location would be the most probable location for organics to be detected. A single grab sample was taken towards the end of each trial burn run.

Flue Gas Sampling (8,9)

Flue gas sampling was conducted (summarized in Table 15) at the incinerator stack to determine emission rates of the following parameters: particulate matter, carbon tetrachloride, trichlorobenzene, hexachloroethane, PCBs, PCDDs/PCDFs, volatile products of incomplete combustion (PICs) and hydrogen chloride.

TABLE 15. FLUE GAS SAMPLING SUMMARY

Parameter	Sampling Method	Length of run	Sample description
PCB, hexachloroethane, trichlorobenzene	MM5	3 1/2 hrs	Probe and front half rinse Filter XAD-2 sorbent Condensate Impinger solution
PCDD/PCDF	MM5	3 1/2 hrs	Probe and front half rinse Filter XAD-2 sorbent Condensate Impinger solution
Particulate/HCl	M5	1 1/2 hr	Probe and front half rinse Filter Impinger solution (HCl analysis only)
Carbon Tetrachloride and other volatile organics (PICs)(a)	VOST	2-3 hrs	3 pr. tubes sampled at 1 LPM for 20 min. 3 pr. tubes samples from integrated Tedlar gas bags for 1 to 1.5 liter total volume
CO, CO_2, O_2 NO_x, THC	CEM	Time required to do all sampling for other parameters	Continuous measurement of flue gas at the exit of the SCC and the stack

(a) PICs quantitated in this program were: methylene chloride, 1,1-dichloroethane, tetrachloroethylene, chloroform, benzene, monochlorobenzene, trichloroethylene, toluene, and 1,2-dichloroethane.

Each test consisted of a 5-hr sampling period that required 8 to 10 hr to execute due to leak checks, teardown of the MM5 sampling trains, and setup of the Method 5 (M5) sampling train. The first 3 1/2 hr consisted of simultaneous sampling of two identical MM5 trains. One train collected a sample for later analyses for dioxins and furans, and the second train collected a sample for later analyses for PCBs, hexachloroethane, and trichlorobenzene. Immediately following this sample period, a 90-min M5 sampling run was completed to measure particulate emissions and HCl. VOST sampling for carbon tetrachloride was completed during the same 3 1/2-hr time period as the simultaneous MM5 trains. The CEM system monitored the stack during the entire sampling period.

The following subsections further describe the protocols utilized.

Method 5--Particulate and HCl

Particulate and HCl testing was conducted from each of the five ports during each sampling period. Each of six equally spaced points were sampled for a 3-min period, totalling 18 min of sampling time per port. Testing utilized a standard M5 Train using an NaOH solution in the impingers instead of deionized (DI) water. The sampling train features are described in the Trial Burn QAPP.

A leak check of the entire sampling train was conducted prior to and at the conclusion of each sampling run, and before and after changing or disconnecting any components of the train during the run.

Modified Method 5 (MM5)--PCBs/Hexachloroethane/Trichlorobenzene and Dioxins/Furans

MM5 sampling trains were used for the collection of polychlorinated biphenyls (PCBs), hexachloroethane, trichlorobenzene and polychlorinated dibenzo-p-dioxins/polychlorinated dibenzofurans (PCDD/PCDF) following the procedures of EPA Method 0010, SW-846, 3rd Edition.

The MM5 sampling was conducted from each of the five ports during each sampling period. Each of six equally spaced points were sampled for a 7-min period, totalling 42 min of sampling time per port.

Additionally, a field-biased blank was set up at the site for each parameter (i.e., one PCB/hexachloroethane/trichlorobenzene field blank and one PCDD/PCDF field blank) during each test day. Each train was set up and recovered as an actual sample but without having sample gas flow through the system. Only one of each type of field-biased blank was analyzed. The sample train is described in the Trial Burn

QAPP. Sampling was isokinetic (± 10 percent) with readings of flue gas parameters recorded at every sampling point during the traverse.

Volatile Organic Sampling Train (VOST)

Data collected from VOST samples are used to calculate the destruction removal efficiency (DRE) for carbon tetrachloride (CCl_4) and the concentrations of volatile organic PICs. The approach developed in the field by Alliance personnel and the regulatory observers featured operation of the VOST train at two different sample volumes. CCl_4 was fed in sufficient quantity to prove greater than 99.9999% (6-9's) DRE. However, a method was required to provide acceptable data should the actual DRE be significantly lower than 6-9's. Such a situation could have CCl_4 concentrations that were above the calibration range of the analytical instrument. The specified sample volumes were based upon the known levels of CCl_4 spiked into the various waste feed streams.

Initially, the VOST unit was operated at a flow rate of 1.0 Lpm for 20 min. Three 20-min samples, collected at 1.0 Lpm within a 2-hr time frame constituted one VOST run. These approximately 20-L samples comprise the "high" VOST runs. These would provide sufficient sensitivity to prove 6-9's DRE.

Subsequently, the VOST unit was operated at a flow rate of 0.3 Lpm for a 42-min into a Tedlar bag to obtain an integrated sample. Then a 1.5L sample was drawn from the bag through the VOST. Three samples, collected in this way constitute one "low" VOST run. A total of six sets of VOST samples plus one set of blank tubes were collected during each run.

ANALYTICAL PROCEDURES

The analyses completed for each trial burn sample are listed in Table 16. The procedures and reference methods for these analyses are summarized in Table 17. All of the analyses for calculation of DREs were conducted by Gas Chromatograph/Mass Spectrometer (GC/MS). The standard methods are discussed in the QAPP, and further discussion is not provided in this report. Special procedures or other considerations related to the other analyses are discussed below.

Analyses for polychlorinated biphenyls (PCBs) were conducted by the GC methods presented in SW-846 (Method 8080) and by the GC/MS methods in EPA Method 680. For those streams that require delisting analysis (Cyclone Ash, Kiln Ash, CPI Separator Sludge, and Purge Water) the appropriate method was determined to be Method 8080 contained in SW-846. This method determines PCBs as Aroclor mixtures. The remaining aqueous

TABLE 16. ANALYSES COMPLETED FOR TRIAL BURN SAMPLES(a)

Sample Name	Analyses(c)
Auxiliary fuel	Density, heat content, elemental (C,H,N,O,S), ash content, CCl_4, C_2Cl_6, TCB, PCDD/PCDF, PCB's and Volatile PICs
Organic liquid feed	Heat content, elemental (C,H,N,O,S), ash content, CCl_4, C_2Cl_6, TCB, PCDD/PCDF, PCB's and Volatile PICs
Solids feed	Elemental (C,H,N,O,S), ash content, CCl_4, C_2Cl_6, TCBs, PCBs, PCDD/PCDF
Kiln ash	CCl_4, C_2Cl_6, TCBs, PCBs, PCDD/PCDF, Delisting,(d) Volatile PICs
Cyclone ash	CCl_4, C_2Cl_6, TCBs, PCBs, PCDD/PCDF, Delisting, Volatile PICs
Makeup water	CCl_4, C_2Cl_6, TCBs, PCBs, PCDD/PCDF, Volatile PICs
Scrubber water(b)	CCl_4, C_2Cl_6, TCBs, PCBs, PCDD/PCDF, Delisting, Volatile PICs
CPI Sludge	CCl_4, C_2Cl_6, TCBs, PCBs, PCDD/PCDF, Delisting
Alkaline feed	CCl_4, C_2Cl_6, TCBs, PCBs, PCDD/PCDF
Stack gas - VOST	CCl_4, Volatile PICs
Stack gas - MM5	C_2Cl_6, TCBs, PCBs, PCDD/PCDF
Stack gas - M5	Particulates, HCl
Combustion gas monitor	CO, CO_2, O_2, NO_x, THC
Stack gas monitor	CO, O_2, NO_x, THC

(a) Standard wastewater analyses (TOC, TSS, TDS, pH, etc.) are not included in this table.

(b) Identical analyses were perfomed for the Quench Water and Scrubber Water prior-to-run matrices with the exception of the Delisting analyses.

(c) PCDD/PCDF analysis includes the quantification of the tetra through octa chlorinated dioxin and furan compounds (typical for all sample matrices). For the effluent streams (stack gas and delisting process samples) where tetra dioxin or tetra furan were detected, the quantification of the 2, 3, 7, 8 substituted isomer was also completed.

(d) Delisting Analysis includes volatile organics, semivolatile organics and EP Toxicity. For the list of compounds included in the Delisting Analysis see Section 5.

TABLE 17. SUMMARY OF ANALYTICAL PROCEDURES AND METHODS

Analysis	Reference Methods(a)
Density	Gravimetric/volumetric
Heat content	A006, ASTM D240
Ash content	A001, ASTM D482
Elmental Composition (C, H, N, O, S)	A003, ASTM 3178
Total chlorine	A004, ASTM D808
Water	ASTM D95
Total suspended solids	EPA M160.1
Total dissolved solids	EPA M160.2
Total organic carbon	EPA M415.1
Organics	
CCl_4 (POHC) and Volatile PICs	A101a, SW8240
C_2Cl_6 and Trichlorobenzene (POHCs)	A121, SW8270
PCBs (POHCs)	
Feeds and stack gas	A121, EPA 680(b)
Residue streams	SW 8080
PCDD/PCDF(semivolatile PICs)	SW8280

(continued)

TABLE 17. (continued)

Analysis	Reference Methods(a)
HCl	EPA M300.0
Particulates	EPA Method 5
O_2, CO_2	EPA Method 3 (ORSAT)
CEM	See Sampling and Monitoring Procedures

(a) "A" refers to Sampling and Analysis Methods for Hazardous Waste Combustion, EPA-600/8-84-002, February 1984.

"ASTM" refers to American Society for Testing Material Standards.

"SW" refers to Test Methods for Evaluating Solid Waste, SW-846, Third Edition, 1986.

"EPA" refers to New Source Performance Standards, Test Methods and Procedures, Appendix A, 40 CFR 60.

"EPA M" refers to Chemical Analysis of Water and Wastes, EPA-600/4-79-020.

(b) Modified Method 680 for Special Analytical Services Test, Identification and Measurement of Pesticides and PCBs by Gas Chromatography/Mass Spectrometry, November 18, 1985. USEPA, EMSL, Cincinnati, Ohio.

streams (makeup water and quench water) were also analyzed by Method 8080 for consistency. Any PCBs contained in the stack gas would not exhibit Aroclor patterns and therefore EPA Method 680 was determined to be more appropriate. The analysis by EPA Method 680 identifies and quantifies homologues (cogeners) in the mono- to deca-chlorinated biphenyl groups, which are summed and reported both as homologues and as total PCBs. Therefore, for all streams involved in DRE calculations (stack, solid feed, and liquid feed) Method 680 was used to quantify PCB content.

QA SUMMARY

The Mobile Incineration System Trial Burn had a well-defined quality assurance/quality control program to ensure the collection of accurate data. This program was developed as part of the preparation activities and was formalized in the Category II Quality Assurance Project Plan (QAPP) [16,17]. The QAPP defines the procedures to fulfill the requirements of the EPA-RREL (Risk Reduction Engineering Laboratory) 16-point guideline for collecting important research data and to demonstrate compliance with State and Federal regulations. The QAPP underwent review and was submitted for approval to EPA quality assurance officials in Cincinnati and Washington The quality assurance activities were divided into two areas: Part A- operating and combustion parameters [16] and Part B- sampling and analytical parameters [17]. The quality assurance/quality control performance achieved during the trial burn is discussed below.

Operating And Combustion Parameters

The operating and combustion parameters are associated with the incinerator instruments and continuous emission monitors. In general these parameters are measured during both trial burns and routine system operations. Measurement of these parameters is the responsibility of the incinerator operating contractor, Enviresponse, Inc.

Several operating and combustion parameter measurements were of specific concern. The parameter measurements were defined in the QAPP as quality assurance goals and cross checks of critical process variables. The quality assurance goals specified precision, accuracy, and completeness objectives for measurements of operating parameters specified in the trial burn permits. The goals were established using previous trial burn data and manufacturers' specifications for the pertinent instruments. Certain incinerator operating measurements also were cross-checked to increase the confidence level of the data reported. Cross checks were made for the two waste feed rates, solid and liquid. Also an overall consistency check was made of all operating data.

Quality assurance (QA) goals were set in the QAPP to establish acceptance criteria for key operating data. Goals were set for measurements of kiln and SCC temperature, combustion oxygen and air rates, waste feed rates, and SCC oxygen, carbon dioxide, carbon monoxide, and oxides of nitrogen. A summary of the goals and the performance in meeting the goals is shown in Table 17. These goals pertain to the calibrations performed on the specified instruments. Most of the quality assurance goals were met. Some of the QA parameters were not calculated because there were insufficient numbers of repeated calibration points to calculate meaningful statistics.

Failure to obtain sufficient numbers of repeated calibration points to calculate meaningful statistics for some of the instruments was caused by unanticipated repairs of equipment between tests.

The continuous emission monitors were calibrated daily to provide accurate and precise gas composition data. In general, the monitors achieved the specified goals.

The completeness criteria describes how much of the data was valid. As shown in Table 18, these goals were met for all instruments.

The oxygen flow meter was not calibrated during the tests due to the safety concerns involved with handling pure oxygen. The calibration procedures require emptying of the line of oxygen and purging of the line with nitrogen prior to the calibration. The site was not equipped for properly purging the oxygen line prior to calibration.

QA SUMMARY OF ANALYTICAL PARAMETERS

Precision is estimated through analysis of duplicates, blank spike duplicates, and matrix spike duplicates. Accuracy is estimated through analysis of matrix spikes and "blind audit cylinders." Completeness is the estimate of the generated data judged to be valid based upon comparison of the achieved precision and accuracy with the goals stated in the QA Plan. In this report, completeness is defined as the percentage of samples that meet both the precision objective and the accuracy objective.

QA objectives were established for all analytical parameters for each sample matrix. For the purposes of the demonstrating the capabilities of the MIS to receive a permit, those parameters and matrices that involved the calculation of DRE and the delisting analysis of residue streams are considered most important. Conclusions regarding calculation of DRE and the analysis of waste streams for delisting are presented in the following section.

TABLE 18. QA SUMMARY FOR COMBUSTION AND OPERATING PARAMETERS

Parameter	Precision (%)		Accuracy (%)		Completeness (%)	
	Goal	Actual	Goal	Actual	Goal	Actual
Rotary kiln gas temperature	5	NC	5	1.69	90	100
SCC temperature	5	NC	5	1.46	90	100
Waste oil flow rate	5	NC	5	2.19(a)	90	100
Waste soil flow rate	10	0.0	10	0.0	90	99.0*
Water injection	5	NA	5	NA	90	NA
CO (NDIR)	15(b)	3.15	5	3.52	90	100(c)
CO_2 (GC)	5	0.42	5	0.96	90	100
O_2 (Polarographic)	5	2.31	5	3.37	90	100
NO_x (Chemiluminescent)	10(b)	(d)	10	(d)	90	100
Kiln oxygen feed rate	5	NC	5	NC	90	100
Kiln air feed rate	5	NC	5	2.83	90	100
SCC air feed rate	5	NC	5	2.57	90	100
Combustion gas velocity	5	NC	5	NC	90	100

Precision expressed in terms of relative standard deviation
(standard deviation / mean) x 100%

Accuracy expressed as the percentage difference from true (standard) value
(true value - measured / true value) x 100%

Completeness expressed as the amount of valid data obtained compared to the total amount collected.

NC - Not calculated due to insufficient repeated calibration points for meaningful statistics

NA - Not applicable since no water was injected

(a) - Based upon calibration curve for Test 5 given in Appendix C:
Accuracy = ((true value - calculated value) / true value) x 100%

(b) - Precision of accuracy of CO and NO_x will be ± 15% or 5ppm for CO and ± 10% or 10ppm for NO_x whichever is greater.

(c) - Two CO meters were used. One meter was always working correctly.

(d) - Calibration data to be supplied by the sampling subcontractor.

Conclusions Concerning DRE Calculations

Destruction and removal efficiency (DRE) calculations depend strongly on the quality of analytical data for the principal organic hazardous constituents (POHCs). For this trial burn, the POHCs were: carbon tetrachloride (CCl_4), hexachloroethane (HXE), trichlorobenzene (TCB), and polychlorinated biphenyls (PCB). The critical concentrations for DRE calculations are those in the feed streams and in the stack gases. The QA summary for DRE analyses is presented in Table 19 and is discussed below.

CCl_4 --

VOST QC data for CCl_4 in blank spike duplicates show a precision of 1 to 3 relative percent difference. Accuracies ranged from 86% to 128% recovery. For CCl_4 in liquid feed matrix spike duplicates, precision values ranged from 2 to 18 relative percent difference (RPD). Accuracies ranged from 68% to 140% recovery. All of these values met the QA objectives. The QC data for the calculation of CCl_4 DRE was excellent.

HXE/TCB METHOD 8270 --

Only MM5 analytical QC data was collected. It was not feasible to spike MM5 trains with HXE or TCB. Due to stack size, it also was not feasible to perform simultaneous replicate MM5 runs. Therefore, it is not possible to directly assess sampling precision or accuracy. However, recovery of HXE from XAD-2 resin was demonstrated by spiking five blank samples with HXE and obtaining MS/MSD data. As shown in Table 19, recovery was excellent and all samples met QA objectives. HXE and TCB were spiked in the solid feed at concentrations less than 1% of the concentrations in the original sample, i.e., too low to determine accuracy. Rather, the MS/MSDs were treated as duplicate samples and precision values which met the QA objective were calculated.

The MS/MSD data for the liquid feed presented in Table 19 indicate excellent QA results.

In summary, both HXE data and TCB data were adequate for DRE calculations.

PCB Homologues Method 680 --

In general, QC results for the PCB Homologues (Method 680) did not meet the QA objectives for the sample matrices analyzed. Many samples were spiked below the method detection limits, and therefore the calculation of estimates of precision and accuracy was not possible. The solid and liquid feeds were spiked below the sample concentration, and thus the estimates of precision and accuracy indicate a high degree of variability. However, as discussed below, the PCB Method 680 QC data shows that the analytical results for PCBs are adequate to provide order of magnitude results for PCB DREs. Order of magnitude results are sufficient to demonstrate that

TABLE 19. QA SUMMARY FOR DRE

POHC	Precision (%) Goal	Precision (%) Actual	Accuracy (%) Goal	Accuracy (%) Actual	Completeness (%) Goal	Completeness (%) Actual
CCl_4 (VOST)	≤ 50	1-3	50-150	86-128	90	100
(liquid feed)	≤ 25	2-18	60-140	68-140	90	100
HXE (XAD-2)	≤ 30	0.4-9.1	30-120	69-80	90	100
(solid feed)	≤ 30	23	30-120	(a)	90	(a)
TCB (solid feed)	≤ 30	37	30-120	(a)	90	(a)
(liquid feed)	≤ 30	9	30-120	73-79	90	100
PCB's (Method 680)						
XAD-2 Tetra	≤ 30	-	75-125	0	90	0
XAD-2 Penta	≤ 30	200	75-125	0-80	90	0
XAD-2 Hexa	≤ 30	22	75-125	90-115	90	100
Solid feed Penta	≤ 30	82	75-125	(b)	90	0
Solid feed Hexa	≤ 30	75	75-125	(b)	90	0
Solid feed Hepta	≤ 30	70	75-125	(b)	90	0
Liquid feed Penta	≤ 30	56	75-125	81-187	90	0
Liquid feed Hexa	≤ 30	20	75-125	163-275	90	0
Liquid feed Hepta	≤ 30	25	75-125	41-194	90	0

(a) The solid feed matrix was spiked with hexachloroethane and trichlorobenzene at levels significantly below the sample concentration. Therefore, accuracy and completeness could not be determined. The matrix spike duplicate pair were treated as a duplicate sample for the measurement of precision.

(b) The solid matrix was spiked with PCBs at levels that were less than 20% of the sample concentration. The liquid matrix was spiked at levels of the same order of magnitude as the sample concentration. Therefore, accuracy was not determined for the solid feed and completeness was not determined for both the solid and the liquid feeds. The solid feed matrix spike duplicate pair was treated as a duplicate sample for the measurement of precision.

Order of magnitude results are sufficient to demonstrate that 99.9999% DRE was achieved because of all PCBs DREs were at least an order of magnitude better than 99.9999% for this trial burn.

QC data for the waste feed samples is presented in Table 19. Samples were spiked with Aroclor 1260, which was the PCB source for the trial burn. For liquid feed, spiking concentrations were of the same order of magnitude as sample concentrations. Recoveries for the penta-, hexa- and heptachlorobiphenyl homologues ranged from 41% to 275%. Precision ranged from 20% to 56%. For these three homologues, accuracy and precision are sufficient for order of magnitude DRE calculations.

For solid feed, spiking concentrations were all less than 20% of sample concentrations. These levels were the maximum concentrations achievable on 0.3 grams of sample with the highest concentration of spiking solution available (10,000 ppm). It is apparent that the very high concentrations of available spiking solutions prevent one from spiking at high enough concentrations to obtain spike recovery data. Rather, the MS/MSDs were treated as duplicate samples and precision values were calculated.

These precision values are acceptable for order of magnitude DRE calculations.

The reasonable agreement between the analytical results and the known values of PCBs in the surrogate feed material prepared for the trial burn further supports the conclusions on DRE.

Estimates of the Precision and Accuracy of the MM5 PCB analysis by Method 680 were obtained from the analysis of three blind XAD resin samples provided by the Office of Toxic Substances. These samples contained tetra through hexa chlorinated biphenyls and tetra through hexa chlorinated dioxins and furans. The audit results are summarized as follows. Percent recoveries for tetrachlorobiphenyl were zero percent for both samples A and B. Percent recoveries for pentachlorobiphenyl were 0% and 80% for samples A and B, respectively. Percent recoveries for hexachlorobiphenyl were 90% and 115% for samples A and B, respectively. The precision value for hexachlorbiphenyl was 22%, which met the QA objective of 30% RPD. Sample C was a blank sample and the analysis indicated not detected (ND) for all homolog groups. This data indicates excellent recovery for the hexa homolog, marginal recovery for penta, and unacceptable recovery for the tetra homolog. However, the Aroclor 1260 used as feed material does not contain significant quantities of the tetra homolog and these results do not directly reflect on DRE calculations.

In summary, the PCB 680 Method QC data is marginally acceptable for the purposes of DRE calculations. Low spiking concentrations of the feed streams and the failure to recover all of the homologs in the blind MM5 audit samples prevent the calculation of estimates of precision and accuracy for these matrices. The data is sufficient to provide order of magnitude results for the DRE of PCBs based upon the agreement between the analytical and known concentration of the surrogate feeds and the excellent MM5 QC data of the hexachlorobipenyl homolog, which is a primary component of the Aroclor 1260.

Delisting Analysis of Residue Streams

Waste stream analyses for PCDD/PCDF, metals PCBs as Aroclors (Method 8080), and volatile and semivolatile organics were required to satisfy delisting criteria. The QA summary for delisting analyses is presented in Table 20 and is discussed below.

PCDD/PCDF--

MS/MSD data for PCDD/PCDFs were completed for scrubber water, cyclone ash, kiln ash, and separator sludge. For scrubber water, precision values ranged from 0% to 10% RPD and accuracy values ranged from 76% to 102% recovery, all of which met the QA objectives. For cyclone ash and separator sludge, precision values ranged from 0% to 36% RPD, and accuracy values ranged from 68% to 170% recovery, which are reasonable values for these matrices. However, the kiln ash sample was reported as a "very dirty sample causing varying spike recoveries, ratios out of range." Precision values ranged from 4% to 153% RPD, and accuracy values ranged from 46% to 1081% recovery, which are inadequate for precise quantification of PCDD/PCDF in kiln ash.

PCBs Method 8080 Delisting--

Matrix spike duplicates were analyzed for cyclone ash, kiln ash, and separator sludge. Spike concentrations ranged from 1.7 for sludge to 102 ug/g for kiln ash. Precision values ranged from 12% to 45%. Two of the three spike recovery values met the QA objective of 30% RPD. Accuracy values ranged from 16% to 98% recovery. Sixty-seven percent of the recovery values met the QA objective of 75% to 125% recovery. Both kiln and cyclone ash met all QA objectives. The separator sludge did not meet the objectives; however, with a delisting limit of 50 ug/g, the data is adequate for delisting purposes.

A duplicate scrubber water sample was analyzed in conjunction with a blank. Reported concentrations for the scrubber water sample were all "not detected," i.e., less than 0.52 ug/L. Reported concentrations for the scrubber water sample duplicate were "not detected" except for Aroclor 1260

TABLE 20. QA SUMMARY FOR DELISTING ANALYSES

	Precision (%)		Accuracy (%)		Completeness	
	Goal	Actual	Goal	Actual	Goal	Actual
PCDD/PCDF						
Water	≤ 50	0-10	40-120	76-102	90	100
Kiln ash	≤ 50	3-153	40-120	46-1081	90	30
Cyclone ash	≤ 50	14-31	40-120	69-144	90	50
Sludge	≤ 50	0-36	40-120	68-170	90	90
EP Toxicity Metals						
Water	≤ 20	0-135	-	-	-	62 (a)
Kiln ash	≤ 30	5-16	80-120	84-104	90	100
Cyclone ash	≤ 30	0-2	80-120	83-102	90	100
Sludge	≤ 30	8-58	80-120	84-123	90	78 (a)
PCBs (Aroclors)						
Water	-	-	-	-	90	(b)
Kiln ash	≤ 30	12	75-125	88-98	90	100
Cyclone ash	≤ 30	22	75-125	76-95	90	100
Sludge	≤ 30	45	75-125	16-25	90	0
VOLATILES						
Water	≤ 25	2	75-125	104-106	90	100
Kiln ash	≤ 25	4	60-140	94-98	90	100
Cyclone ash	≤ 25	4	60-140	100-104	90	100
Sludge	≤ 25	4	60-140	94-98	90	100
SEMIVOLATILES						
Water	≤ 30	153-200	40-110	0-128	90	0
Kiln ash	≤ 30	(c)	30-120	(c)	90	0
Cyclone ash	≤ 30	20	30-120	22-27	90	0
Sludge	≤ 30	22-75	30-120	41-124	90	0

(a) Accuracy for water was not determined. Precision ranged from 0% to 37% Relative Percent Difference when mercury is discounted. Mercury concentrations were close to the detection limit.

(b) No data available for water.

(c) Laboratory spiked matrix at method detection limit; too low to recover spiking compound.

which is reported at 0.91 ug/L. Reported concentrations for the associated blank sample were all "not detected," i.e., less than 0.52 ug/L. It was not possible to estimate precision from these data.

Volatiles for Delisting

Carbon tetrachloride was analyzed as a delisting parameter. A total of seven laboratory blanks were analyzed; reported concentrations were "not detected", i.e., less-than 10 ug/L for carbon tetrachloride and less than 5 ug/L for chloroform.

For scrubber water, one duplicate pair of samples was analyzed. Reported concentrations were "not detected."

For scrubber water, kiln ash, cyclone ash, and separator sludge, matrix spikes and matrix spike duplicates were analyzed. Calculated precision values were all less than the QA objective of $\leq$ 25%. All of the percent recovery values fall within the QA objective of 60 to 140%. Estimated overall completeness for volatiles delisting parameters is 100%.

EP Toxicity Metals

Precision for EP Toxicity metals was determined by the analysis of duplicate samples. Accuracy was determined by the analysis of matrix spikes. As indicated in Table 20, all of the accuracy results met the QA objective for all metals (8 EP Toxicity metals plus nickel). Precision values showed wide variability, particularly for the scrubber water and sludge samples. This variability was due to the sample concentrations being near the detection limit in many cases. Based upon the accuracy results, the EP Toxicity analysis was adequate for delisting purposes.

OBSERVERS AND AUDITS

The trial burn sampling program was witnessed by representatives of the Missouri Department of Natural Resources (MDNR), EPA Region VII and the Office of Toxic Substances (OTS). The observers witnessed at various times all aspects of the trial burn program including the following:

- Preparation and sampling of feed materials
- Sampling of process and residue streams
- Review process operations including system operating parameters and data collection
- Stack sampling activities including sampling train set-up, leak checks, collection of blank samples, sampling train recovery, and data collection
- Perform and observe audits of the VOST system and the Continuous Emission Monitors (CEM)

- Review of facility records and procedures

Audits

Audits of both the field sampling activities and the analysis of the samples at the laboratories have been included in the trial burn program. The various audit programs and results are presented below.

Technical Systems Review --
A Technical Systems Review (TSR) has been conducted at Alliance Technologies Corporation located in Bedford, Massachusetts. This TSR was conducted by the Hazardous Waste Engineering Research Laboratory (HWERL) on August 13 and 14, 1987. A follow-up TSR was conducted on September 24 and 25. The reviews were completed by W. Burton Blackburn of S-CUBED, La Jolla, California.

The initial TSR identified areas of concern, which were categorized as either critical, major, or minor. Based upon the corrective actions taken by Alliance and the additional information supplied by Alliance and their subcontractor laboratories, all of the critical and major concerns were eliminated or reduced to minor concerns. In addition, many of the minor concerns were also eliminated.

The Review Summary concludes:

> "Since only minor concerns remain and most of the previous corrective action recommendations have been satisfactorily implemented, the rating for the Technical Systems Review of Alliance for the laboratory portion of this project is revised to Acceptable with Qualifications. Although some additional recommendations are noted in this report, and were discussed with Alliance, no additional corrective action recommendation forms have been issued. Minimum criteria have been satisfied and acceptable data quality seems likely."

Audit of VOST--
Three sets of VOST tubes were sampled prior to Test 3 from a blind audit cylinder obtained from Research Triangle Institute (RTI). The VOST Audit was requested by EPA Region VII and monitored in the field by the regulatory observers. As shown in Table 21, audit accuracy ranged between +23% to -28% for all compounds analyzed. This accuracy is well within the ± 50% goal specified in the QAPP for volatile analysis.

TABLE 21. RESULTS OF VOST SYSTEM AUDIT

Compound	Auditee Conc. (ppmv)	RTI Conc. (ppmv)	Audit % Bias(a)
Carbon Tetrachloride	229	291	-21
Chloroform	174	232	-25
Perchloroethylene	264	365	-28
Benzene	368	300	+23
Vinyl Chloride	N/A	312	N/A

(a) Audit Accuracy expressed as % Bias $= \frac{\text{Auditee conc - RTI conc}}{\text{RTI conc}} \times 100$

Audit of Sampling Activities--

The trial burn program was subjected to an extensive audit program by the OTS observers and Mr. Paul Gorman of Midwest Research Institute. During the demonstration test the following activities were performed:

1. Observation and Audit of process operations.
2. Observation and Audit of the process and stack sampling.
3. Collection of duplicate process samples for independent analyses.
4. Completion of performance audits of continuous emission monitoring instruments and stack sampling equipment.

Subsequent to the trial burn an audit was issued by Mr. Gorman [5]. In summary, it concludes that "all of the audit results were acceptable, with the possible exception of the GC CO monitor. No sampling procedures were observed which would compromise the validity of the data". It should be noted that the GC CO monitor is the back-up system for the NDIR continuous CO monitor.

Performance audits were conducted on the following equipment:

CO Monitor for quench elbow location (NDIR and GC)
O_2 and Co_2 monitor for quench elbow Location
CO monitor for stack location (NDIR)
O_2 monitor for stack location
O_2 and CO_2 for Orsat Apparatus
Barometric pressure
Stack sampling console flow rates (two consoles)

The results of the performance audits are contained in Table 22.

Audit of metaTrace Laboratory--

OTS has supplied samples containing unknown concentrations of dioxins, furans, and PCBs to the metaTrace Laboratory in St. Louis, Missouri. The audit showed that recovery of PCBs would be adequate to establish DREs although individual homologs, specifically tetrachlorobiphenyl and pentachlorobiphenyl, showed detection problems. Dioxin and furan recovery were adequate to establish PICs concentrations.

TABLE 22. OTS/MRI PERFORMANCE AUDIT RESULTS

Equipment audited	Parameter	Reading of device audited	Expected audit value	Relative accuracy(a) (%)
CO monitor for quench elbow				
NDIR	CO (ppm)	46	50	-8.0
GS	CO (ppm)	37	50	-26
O_2 monitor for quench elbow				
Polarographic	O_2 (%)	4.9	4.89	0
GC	O_2 (%)	4.85	4.89	-0.90
CO_2 monitor for quench elbow				
GC	CO_2 (%)	5.35	4.99	+7.2
CO monitor for stack (NDFR)	CO (ppm)	56	50	+12
O_2 monitor for stack	O_2 (%)	17.2	17.1	+0.6
Orsat				
O_2	O_2 (%)	17.8	17.1	+4.1
CO_2	CO_2 (%)	3.0	3.0	0
Barometric pressure (based on phone call to airport, corrected for elevation)	B.p. (in. Hg)	28.52	28.38 (barometer)	+0.50
Console no. 2550	Flow (scfm)	0.310	0.305	+1.6
Console no. 2180	Flow (scfm)	0.305	0.305	0

(a) Relative Accuracy = $\frac{\text{Reading - Audit Value}}{\text{Audit Value}} \times 100$

SECTION 7

FEASIBILITY TESTING WITH VERMICULITE AND BROMINATED SLUDGES

EPA proposed to incinerate large quantities of dioxin-contaminated pesticides (actually herbicides) and brominated sludges in the MIS. Since these materials differ in properties from the soil and trash materials normally processed in the MIS, it was necessary to plan and execute a series of tests to determine the feasibility of successfully processing them. Although the tests were successful, the pesticides were not incinerated in the MIS.

HERBICIDE-CONTAMINATED VERMICULITE

The combined results from the trial burn and supplemental tests show that the dioxin-contaminated pesticides, which are applied to a vermiculite matrix, could be processed successfully by the MIS. The trial burn showed that the MIS successfully could meet the 99.9999% DRE requirement for the herbicides. The supplemental tests discussed below showed that uncontaminated vermiculite could be processed up to 736 lb/hr without exceeding the allowable 0.08 gr/dscf particulate emissions.

Herbicide Characteristics

The herbicides are commercial preparations whose registrations have been suspended by the EPA due to their toxicity and the toxicity of trace quantities of dioxin, an unwanted byproduct of the herbicide manufacturing process. Over 99% of the herbicides is Weedone^R granular weed-killer. Weedone^R consists of approximately 93% vermiculite, an inert carrier ingredient; 3.2% 2,4-Dichlorophenoxyacetic acid (2,4-D); 1.6% 2,4,5-Trichlorophenoxyacetic acid (2,4,5-TP); and 1.5 ppb of 2,3,7,8-TCDD. Vermiculite is a very light and porous solid weighing 6 to 7 lb/ft^3.

Test Considerations

Due to the vermiculite's low bulk density, there were two concerns to be addressed:

1. Was an adequate feedrate achievable? Feedrate could be limited either by the ram feeder or by the volume capacity of the kiln. The ram feeder pushes about 1.2 ft^3 of solid waste into the rotary kiln each time it cycles and its maximum cycling frequency is about twice a minute. The volume capacity of the kiln is determined by the amount of material that can be held by the kiln without overflowing the corbel. The corbel is an annular lip on the front end of the

kiln that rotates with the kiln. There is a space between the corbel and the front plate of the kiln. When material gets into this space, the seals of the kiln are damaged.

2. Would excessive particulate emissions limit feedrates? Since the vermiculite is very light, it could be picked up by flue gas currents inside the kiln and be carried over to the rest of the system.

The above questions were answered by performing both capacity and particulate tests.

Vermiculite Test Results

Capacity and particulate tests using uncontaminated vermiculite of the same type as the herbicide-contaminated vermiculite (Grade 3) demonstrated that the MIS could handle this material adequately. The capacity test showed that the incinerator could achieve a feedrate greater than 600 lb/hr. During this test, ash was removed from the system at a ratio of 6 barrels of kiln ash to 1 barrel of cyclone ash. This was comparable to the ratio for the dusty Erwin Farm soil. Since the MIS could handle the Erwin Farm soil without excessive carryover, it is likely that carryover would not be a problem with vermiculite. These results were used to set feed rates for the particulate emission tests. At average vermiculite feed rates of 736 lb/hr and 437 lb/hr, the measured particulate emissions were 0.015 and 0.021 gr/dscf respectively, corrected to 12% CO_2 (0.014 and 0.019 gr/dscf corrected per the MIS operating permit). These were well below the 0.08 gr/dscf regulatory limit. Operating conditions are given in Table 23 and particulate emissions results are given in Table 24.

Rotary Kiln Temperature For Vermiculite

During the particulate testing, some slagging was noticed inside the rotary kiln. Slagging decreases availability of the unit because it must be shut down to remove the hardened slag. The slagging could have been caused either by the trash fed on the days prior to the particulate test or by the vermiculite. Since a difference of 100 to 200°F in the kiln temperature can greatly affect slagging rates, a bench scale thermal exposure study was performed on vermiculite. This study showed that vermiculite manifests the initial signs of fusion at 2000°F. This behavior provides adequate margin above the normal rotary kiln temperatures, which range from 1400°F to 1800°F.

The thermal exposure tests subjected vermiculite samples weighing 5 to 6 grams to incineration temperatures of 1600°F, 1800°F, and 2000°F for periods of one hour. In addition, one sample was subjected to a 2000°F temperature

TABLE 23. AVERAGE PROCESS OPERATING CONDITIONS DURING VERMICULITE TESTS

Date (1987) Time (Begin-end) Test Description		Test 1 9/8 21:00-06:01 Vermiculite	Test 2 9/8 23:00-06:38 Vermiculite
GENERAL:			
Total Thermal Load	(10^6Btu/hr)	-	-
Total Oxidation Flow(a)	(SCFM)	-	-
Combustion Efficiency	(%)	-	-
KILN:			
Combustion Temperature	(^oF)	1423	1410
Solid Waste Feed Rate	(lb/hr)	733	407
Liquid Waste Feed Rate	(lb/hr)	NA	NA
Fuel to Oxygen Burner	(lb/hr)	87.0	1.43
Oxygen Flow Rate	(SCFhr)	3152	4100
Vacuum (Draft)	(in w.c.)	0.44	0.49
Oxygen	(%)	13.1	15.74
SCC:			
Combustion Temperature	(^oF)	2132	2141
Combustion Air Flow	(SCFM)	1132	1376
Fuel Flow	(lb/hr)	32.6	40.4
Vacuum (Draft)	(in w.c.)	1.9	2.73
Quench Water Recirc. Flow	(gpm)	59	59
Quench Water pH		8.8	8.5
Gas Exit Temperature	(^oF)	175	175
Oxygen GC	(%)	-	-
Oxygen Polarographic	(%)	-	-
Carbon Dioxide GC	(%)	-	-
Carbon Monoxide GC	(ppm)	-	-
Total Hydrocarbons GC	(ppm)	-	-
Nitrogen Dioxide	(ppm)	-	-
SCC Residence Time(b)	(sec)	3.69	3.17
WEP:			
AC Voltage	(V)	130	130
AC Amperes	(a)	25	25
DC Voltage	(KV)	11	11
DC Milliamperes	(ma)	60.0	60.0
Fluegas	(ACFM)	-	-

(continued)

TABLE 23. (continued)

		Test 1	Test 2
Date (1987)		9/8	9/8
Time (Begin-end)		21:00-06:01	23:00-06:38
Test Description		Vermiculite	Vermiculite
MX SCRUBBER:			
Recirc. Water Flow	(gpm)	95	95
Water Temperature	(°F)	172	170
Scrubber Water pH		8.6	8.7
Scrubber Purge Water	(gpm)	-	-
ID FAN:			
Vacuum (Draft)	(in w.c.)	-	-
STACK:			
Oxygen	(%)(c)	-	-
Carbon Monoxide	(ppm)(c)	-	-
Oxygen Orsat	(%)	10.7	12
Carbon Dioxide Orsat	(%)	9.6	8.4
Total Hydrocarbons	(ppm)	-	-
Nitrogen Dioxide	(ppm)	-	-

(a) (Oxygen flow and air flow to rotary kiln) + air flow to SCC
(b) Calculated from material balance
(c) From continuous emission monitor

TABLE 24. PARTICULATE SAMPLING PARAMETERS AND EMISSIONS SUMMARY - VERMICULITE TESTS

Run	Verm-1	Verm-2	Blank
Date (1987)	9/8	9/8	
Location	Stack	Stack	Stack
Run Time	18:22-20:10	22:00-23:37	
Nozzle diameter, in.	0.372	0.372	0.374
Barometric pressure, in. Hg	30.02	30.02	30.00
Net sampling time, min.	90.0	90.0	90.0
Volume metered, ft^3	40.360	49.171	47.193
Avg. DGM temp., ^oF	105.2	97.2	93.7
Avg. Delta H, in. of H_2O	0.63	0.92	0.78
Avg. Delta H, in. of Hg	0.0462	0.0675	0.0574
DGM calibration factor	0.993	0.993	0.993
Volume of gas collected, dscf	37.624	46.528	44.896
Total water collected, ml	650.4	759.8	696.7
Volume of water vapor, scf	30.666	35.825	32.849
Moisture, % (calculated)	36.4	41.4	41.3
Moisture, % (measured)	44.9	43.5	42.3
Dry mole fraction, (100% - moisture)	0.6359	0.5855	0.5874
CO_2, % dry	9.60	8.40	8.00
O_2, % dry	10.70	12.00	13.00
$CO + N_2$, % dry	79.70	79.60	79.00
Dry molecular weight, lb/lb mole	29.96	29.82	29.80
Wet molecular weight, lb/lb mole	25.61	24.92	24.93
Excess air, %	103.5	133.1	165.5
Stack area, sq. in.	576.0	576.0	576.0
Static pressure, in. of H_2O	1.46	1.46	0.45
Stack pressure, in. of Hg	30.13	30.13	30.03
Avg. stack temp., ^oF	165.4	171.0	170.6
Avg. sq. root of Delta P	0.2793	0.3391	0.3171
SDE average	6.9848	8.5183	7.9632
Pitot coefficient	0.84	0.84	0.84
Stack gas velocity, afpm	1083.6	1339.6	1254.1
Stack flowrate, dry scfm	2343.4	2643.5	2476.1
Stack flowrate, wet scfm	4334.5	5358.3	5016.2
Isokinetics, %	94.5	103.6	105.6
PARTICULATE EMISSIONS SUMMARY			
Total - filter and probe rinse			
Particulate collected, mg	28.56	44.77	54.63
Grain loading, gr/dscf	0.0117	0.0148	0.0187
Grain loading, gr/acf	0.0063	0.0073	0.0093
Grain loading, gr/dscf @ 12% CO_2	0.0146	0.0212	0.0281
Emission rate, lb/hr	0.2348	0.3358	0.3977

for 11.5 hours. Visual examination of the samples afterexposure revealed that the particles in the 1600°F and 1800°F samples were completely separable from each other and no fusion had occurred. However, the 2000°F samples contained many agglomerates of particles which could be broken apart with a minimum applied force. After visual examination the residues were observed in a Scanning Electron Microscope (SEM) to check for local melting or fusion. Scanning electron micrographs of representative particles of the as-received and thermally exposed samples are presented in Figures 15 and 16. The photomicrographs illustrate that, except for a five-to-sixfold ("popcorn") expansion, the particles in the 1600 and 1800°F samples are similar to the as-received vermiculite. The bottom right photomicrograph of Figure 16 shows that localized bonding between two particles has occurred in the 2000°F sample. The surface morphology of this sample is also markedly different from that of the samples exposed to lower temperatures.

BROMINATED SLUDGE TESTS

Feasibility tests with the brominated sludge were necessary because previous testing [4] had shown that this material was difficult to process in the MIS. Specifically, there were feed system problems and slagging problems. The slagging problems can be attributed to sodium sulfate (Na_2SO_4), which was mixed with the sludge. Also, 1000 ppm of organic bromide remained in the ash, and 300 ppm was detected in the purge water. However, the previous testing did show that bromine capture was adequate and that emission of free bromine from the stack would not be a problem. Hence, a program was planned and executed to demonstrate the feasibility of processing the sludge. The program was designed to answer the following concerns:

1. Could the material be processed without the previous feed system problems?

2. Is there a reasonable set of MIS operating conditions that would produce a delistable ash?

3. Can particulate emissions meet the 0.08 gr/dscf regulatory limit?

4. Will addition of small quantities (about 1 wt%) of Na_2SO_4 produce slagging? Addition of sodium to solids produces large decreases in the melting temperature and subsequent slagging [18].

5. Can the rotary kiln flue gas temperature be controlled? Measurements showed that the sludge had significant heating value, which varied from 3200 to 4600 BTU/lb.

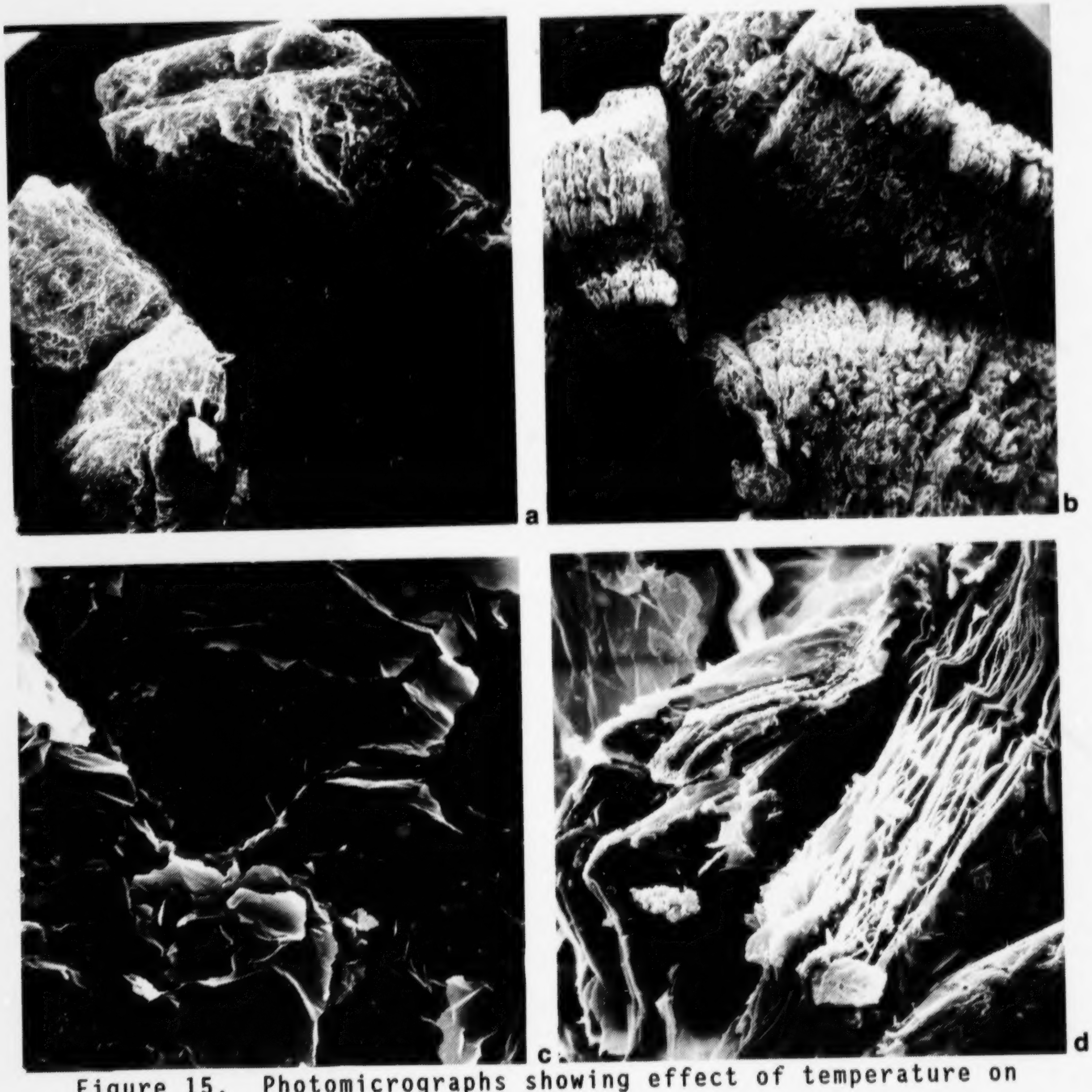


Figure 15. Photomicrographs showing effect of temperature on vermiculite particles.

a) original shape of particles
b) "popcorn" effect at 1800°F
c) original shape at 600x
d) "popcorn" effect at 1800°F

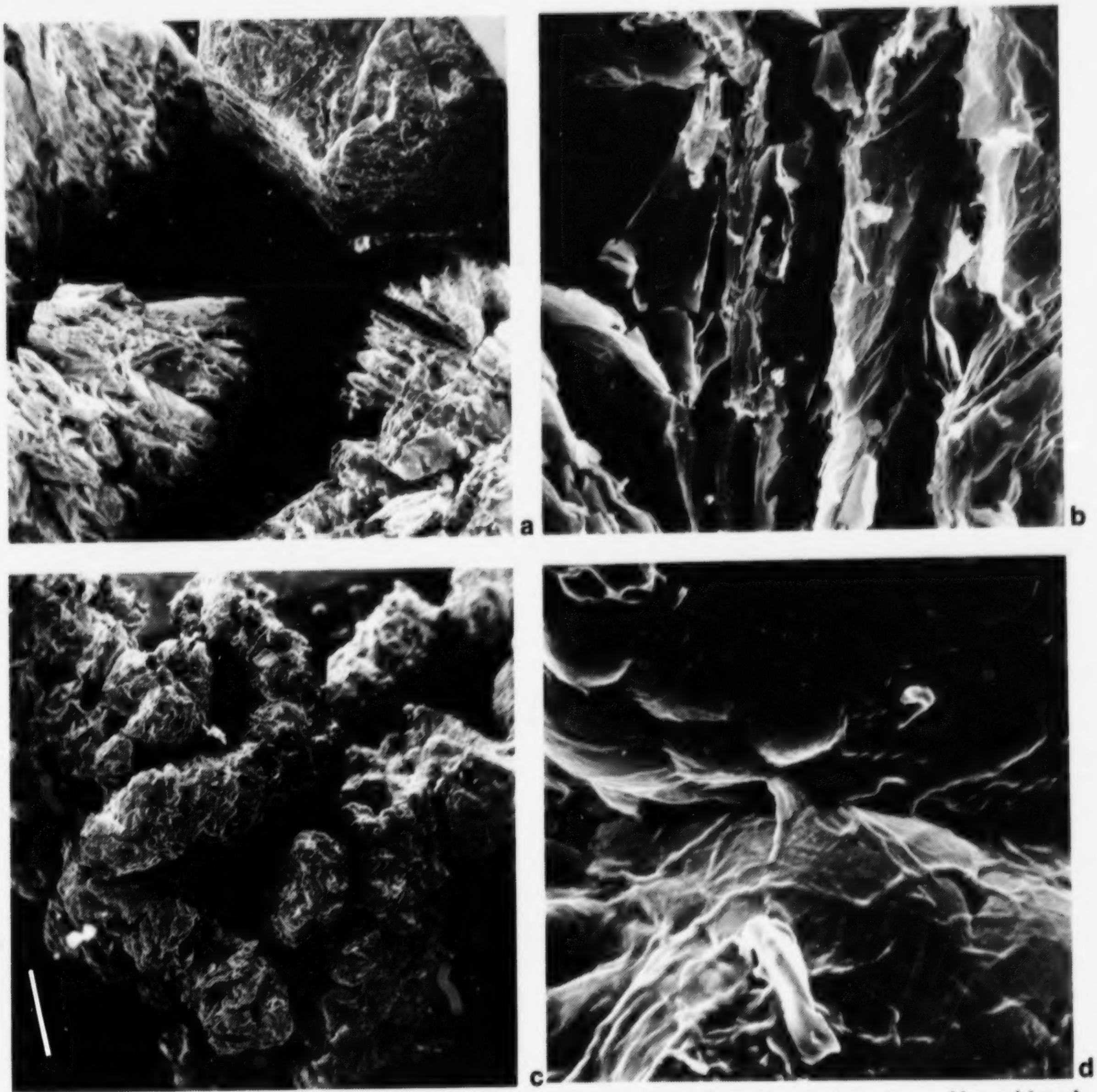


Figure 16. Photomicrographs showing onset of sintering (bonding) for vermiculite particles.

a) particles at 1800°F
b) particles at 1800°F, 600x
c) particles at 2000°F
d) particles at 2000°F, 600x

The program consisted of a series of bench-scale tests to determine the effect of Na_2SO_4 on slagging characteristics of soil and a series of full-scale tests consisting of three tests in September 1987 and seven tests in April 1988. The test program and its results are discussed below.

Brominated Sludge Characteristics

The sludge exhibited a wide variability in characteristics. Analyses, presented in Table 25, show that measured bromine content varied between 1% and 12%; moisture varied between 35% and 42%; ash content varied between 23% and 43%; and heating value ranged from 2600 to 6200 BTU/lb. The material tended to act like dough, and it would produce balls when processed in the kiln.

Na_2SO_4/Soil Bench-Scale Tests

Since it was possible that dioxin-contaminated Na_2SO_4 would be processed with contaminated soil and sludge, a series of bench scale tests were conducted with blends of soil and Na_2SO_4 to ascertain slagging potential. Mixtures containing 1% Na_2SO_4 manifested no signs of fusion up to 1650°F. However, mixtures containing 5% or greater Na_2SO_4 showed an onset of fusion at 1475°F and severe fusion and agglomeration of particles at 1830°F. These tests showed that slagging in the kiln would not be a problem with soil mixtures containing between 1% and 2% Na_2SO_4. Details of the tests are discussed below.

Procedure--

The test procedure consisted of blending mixtures of Na_2SO_4 and soil, exposing each mixture to a series of temperatures, examining the samples with a scanning electron microscope and analyzing selected areas of the sample by EDAX (Energy Dispersion X-ray Analysis). Clean soil from Denney Farm was blended with Na_2SO_4 to form mixtures containing 1%, 5%, 10%, and 30% Na_2SO_4. The soil was representative of the contaminated soils that were processed in the MIS. Each mixture was exposed to temperatures of 1100°F, 1475°F, 1650°F, and 1830°F and examined under the scanning electron microscope.

Results--

The results are described below using a series of photomicrographs, which illustrate the slagging phenomenon. Figure 17 shows the result of exposing 1% Na_2SO_4/soil mixture to 1100°F. The particles in the photomicrographs show no sign of fusion, as manifested by the sharp corners in the individual particles. Onset of fusion is shown for the 5% Na_2SO_4/soil mixture heated to 1475°F in Figure 18. The smaller particles are rounded and are fused to the larger particles. Severe fusion is illustrated in Figure 19 for the

TABLE 25. BROMINATED SLUDGE CHARACTERISTICS

Heating Value	(BTU/lb)	2626 - 6194
Bulk Density	lb/ft^3	77.4
Ash Content	(%)	23.0 - 42.7
Moisture Content	(%)	35.4 - 42.3
Bromine Content	(%)	1 - 12.1

Results of volatile and semivolatile scan conducted on a sample by Southwest Laboratory of Oklahoma on January 2, 1987:

Methylene chloride	(%)	0.1700
Chloroform	(%)	0.0020
1,2-Dichloroethane	(%)	0.0039
Toluene	(%)	0.1588
Ethylbenzene	(%)	0.5370
Total Xylenes	(%)	4.1370
2-Bromo-6-methoxynaphthalene	(%)	0.6440
2-Bromo-6-naphthaleneol	(%)	0.3290
1,1 -Oxybisnaphthalene	(%)	0.2278
Naphthalenes	(%)	0.3000
2,3,7,8-Tetrachlorodibenzo(p)dioxin		0 - 20 ppb

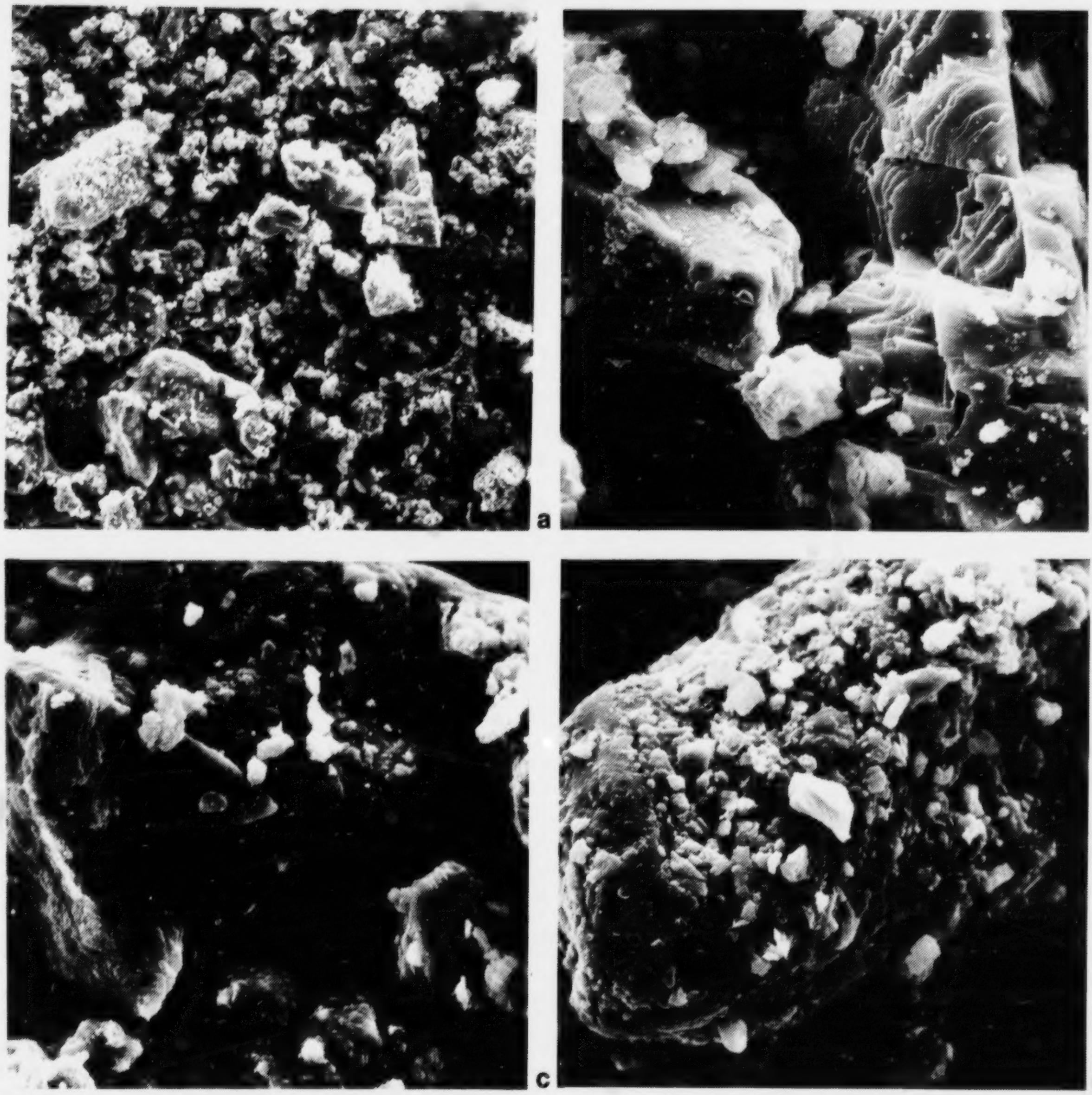


Figure 17. Photomicrographs of 1% Na_2SO_4/soil mixture heated at 1100°F.

a) particles at 300x
b) particles at 1500x
c) particles at 1500x
d) particles at 1500x

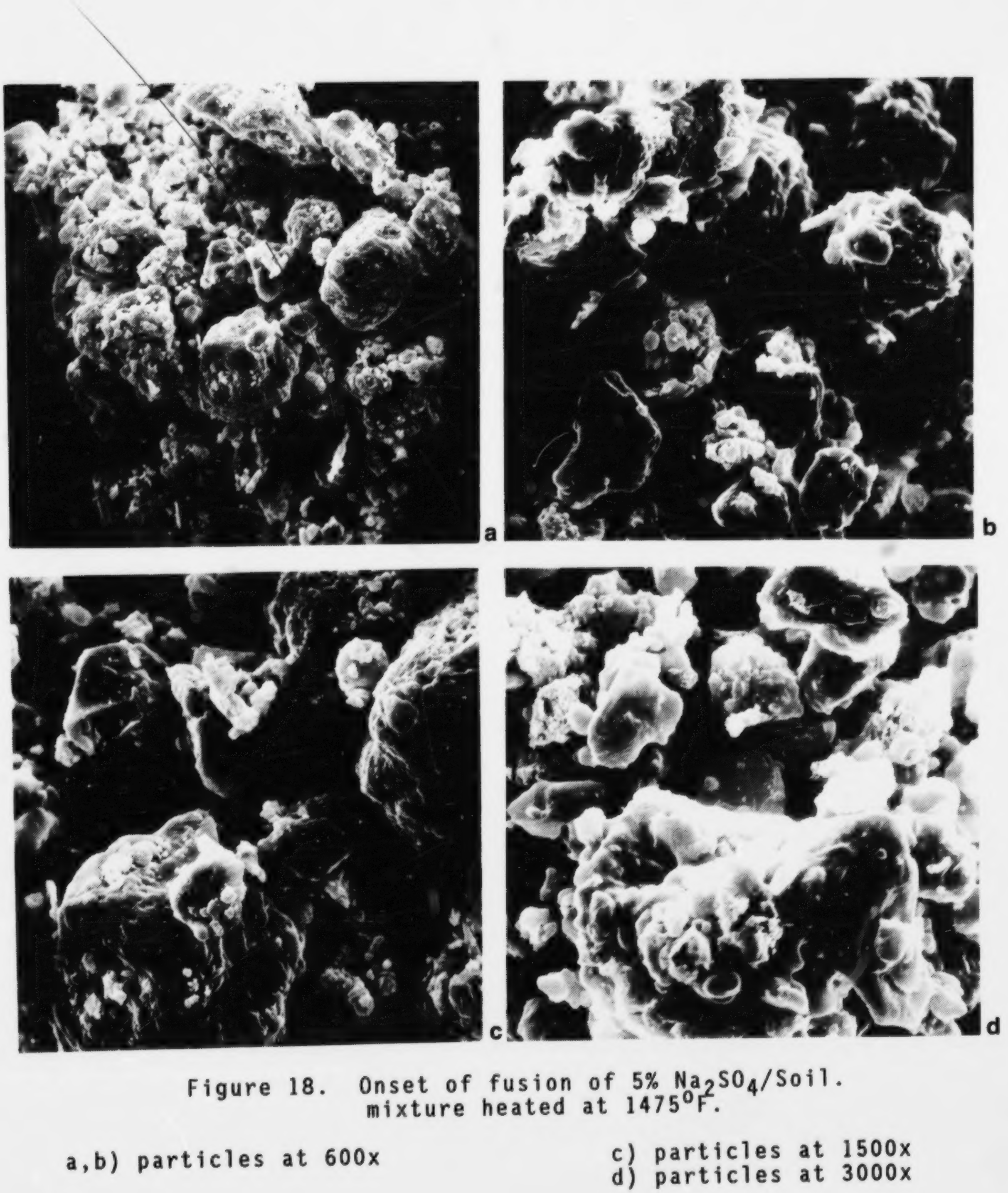


Figure 18. Onset of fusion of 5% Na_2SO_4/Soil. mixture heated at 1475°F.

a,b) particles at 600x

c) particles at 1500x
d) particles at 3000x

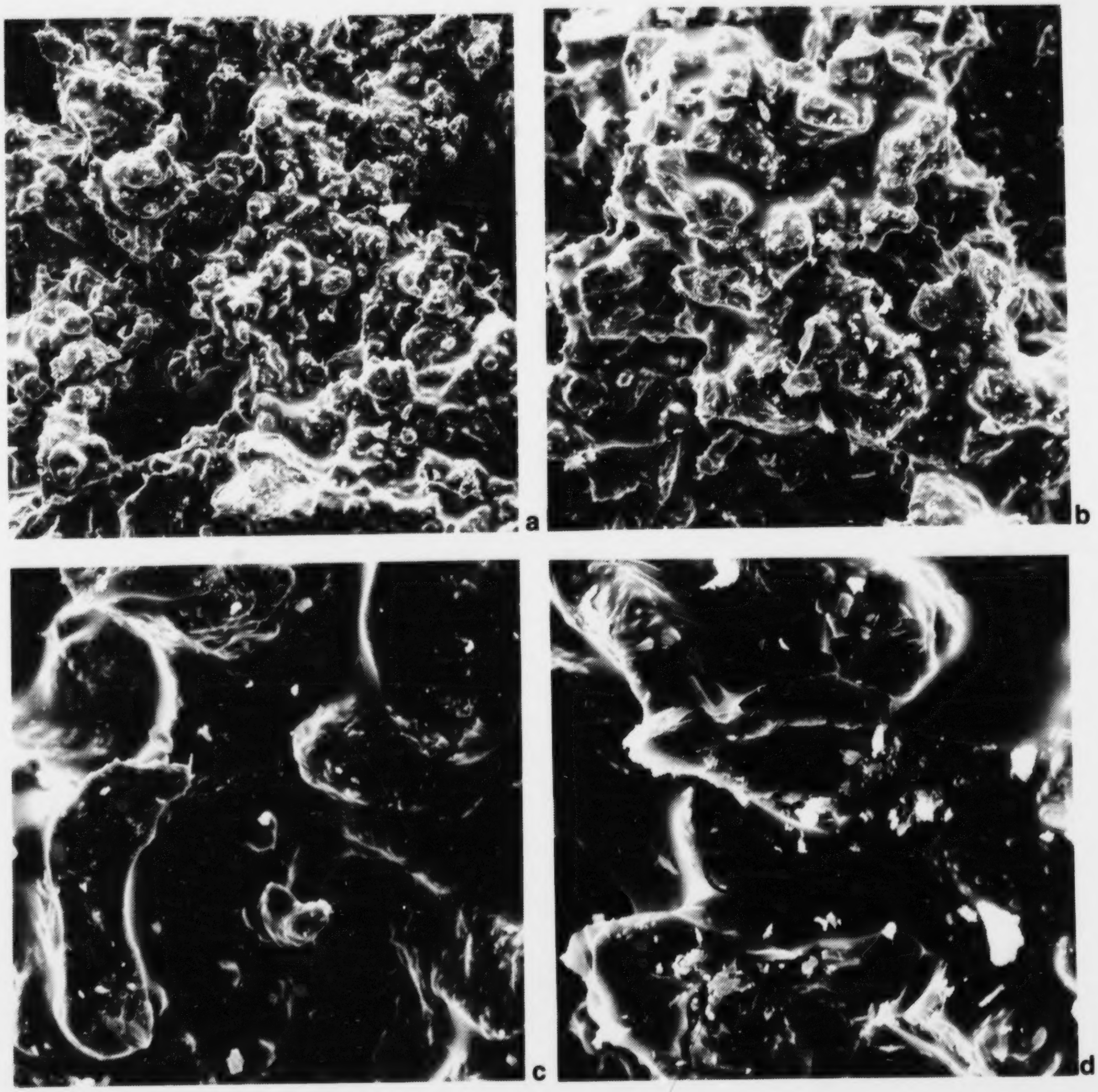


Figure 19. Severe fusion of 10% Na_2SO_4/soil mixture heated at 1830°F.

a) 150x; b) 300x; c) 600x; d) 1500x

10% Na_2SO_4/soil mixture heated to 1830°F. The mixture now contains small particles embedded in a smooth glassy matrix. The composition of the glassy area c and d photomicrographs, is given in Figure 20, an Energy Dispersive Analytical X-ray (EDAX) scan, showing the presence of sodium, potassium, and iron. These elements are known slagging promoters.

Test Conditions in 1987

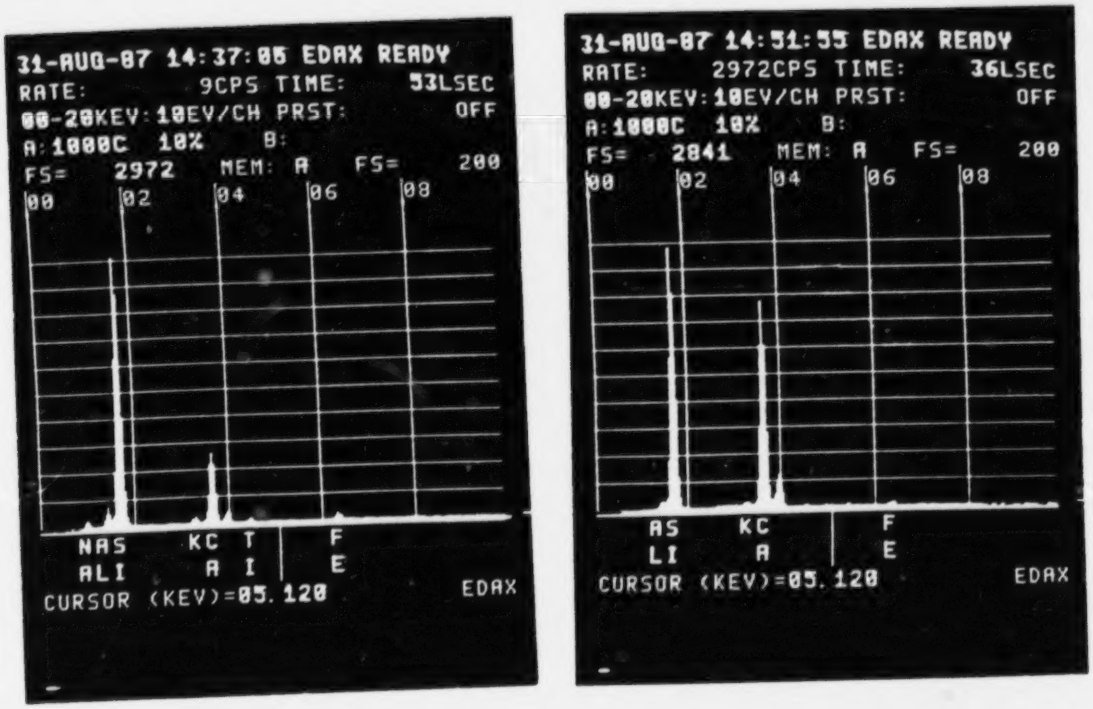
Since control of kiln temperature was considered to be important, the original plan was to blend sludge and soil. The soil was to act as a heat sink to assist in controlling kiln temperature. Therefore, in 1987 the testing examined the effect of blending soil and sludge in different ratios. The blend ratios were selected based upon the availability of contaminated sludge and soil and based upon the heat content of the sludge. A mixture containing about 23% sludge and 1% Na_2SO_4 was run during the first two tests, and a mixture containing about 38% sludge and 1.2% Na_2SO_4 was run during the third test. Feed rates were held relatively constant at 3800 to 4200 lb/hr. Kiln temperature was maintained at 1450°F to minimize slagging and the kiln was rotated at 1.6 rpm. Test conditions are presented in Table 26.

Brominated Sludge Test Results in 1987

The three tests produced mixed results. Physical performance of the unit was generally good, but chemical performance ranged from poor to good. The feed system was able to handle up to 4300 lb/hr of sludge and soil mixture which is equivalent to 1625 lb/hr of sludge material. The unit narrowly failed to meet the delisting criteria for the sludge as discussed below. These results showed great improvement over the test conducted in 1985 [4] because they demonstrated that the modified feed system was adequate, that particulate emissions remained in compliance, and that decontamination of the material was feasible at feed rates much higher than the 973 lb/hr achieved in 1985. However, further testing was required to establish proper processing conditions. These were conducted during 1988. Unit performance during the 1987 tests was as follows:

Feed rate --

Feeding of the 23% sludge mixture during the first two tests was good. Feed rates of approximately 4000 lb/hr were maintained without problems. Although an average feed rate of 4300 lb/hr was achieved for the 38% sludge mixture, the material was in large, doughy lumps. This caused feed rate variations due to the behavior of the feed system as explained below. The feed system operates as follows: Feed rate is controlled by a weight setpoint on the weigh scale and a



```
31-AUG-87 14:37:05 EDAX READY
RATE:          9CPS TIME:     53LSEC
00-20KEV:10EV/CH PRST:           OFF
A:1000C  10%      B:
FS=    2972    MEM: A    FS=     200
```

```
CURSOR (KEV)=05.120              EDAX
```

```
31-AUG-87 14:51:55 EDAX READY
RATE:      2972CPS TIME:      36LSEC
00-20KEV:10EV/CH PRST:           OFF
A:1000C  10%      B:
FS=    2841    MEM: A    FS=     200
```

```
CURSOR (KEV)=05.120              EDAX
```

40 BULK & 40

41

From Energy Dispersive Analytical X-ray (EDAX) scans of the sample.

Figure 20. Composition of slag material: 10% Na_2SO_4/soil mixture heated at 1830°F.

TABLE 26. BROMINATED SLUDGE AVERAGE PROCESS OPERATING CONDITIONS

Conducted 9/2/87		Test 1	Test 2	Test 3
Time (Begin-end)		12:00-13:30	14:35-16:28	18:10-19:40
Test Description		23% Sludge	23% Sludge	38% Sludge
Combustion Efficiency	(%)	99.97	99.98	99.98
KILN:				
Combustion Temperature	(^{o}F)	1416	1424	1440
Solid Waste Feed Rate	(lb/hr)	3925	3601	4278
Sludge Feed Rate	(lb/hr)	902	828	1626
Liquid Waste Feed Rate	(lb/hr)	0	0	0
Fuel to Oxygen Burner	(lb/hr)	115.8	124.9	141.4
Oxygen Flow Rate	(SCFH)	4700	6140	6200
Vacuum (Draft)	(in w.c.)	0.48	0.54	0.49
Oxygen	(%)	10.37	9.96	10.26
rpm		1.6	1.6	1.6
SCC:				
Combustion Temperature	(^{o}F)	2124	2109	2130
Combustion Air Flow	(SCFM)	1453	1498	1520
Fuel Flow	(lb/hr)	35.4	37.6	37.6
Vacuum (Draft)	(in w.c.)	2.49	2.82	2.87
Quench Water Recirc. Flow	(gpm)	54.0	54.0	54.0
Quench Water pH		8.46	8.77	8.77
Gas Exit Temperature	(^{o}F)	175.0	175.0	175.1
Oxygen GC	(%)	8.76	7.07	5.69
Oxygen Polargraphic	(%)	10.36	7.92	6.47
Carbon Dioxide GC	(%)	12.05	14.3	14.19
Carbon Monoxide GC	(ppm)	3.13	2.48	2.80
Total Hydrocarbons GC	(ppm)	0.68	0.82	1.02
Nitrogen Dioxide	(ppm)	177.0	166.1	152.0
SCC Residence Time(a)	(sec)	2.53	2.09	2.05
WEP:				
AC Voltage	(V)	130.0	130.0	130.0
AC Amperes	(a)	25.0	25.0	25.0
DC Voltage	(KV)	10.5	10.75	10.88
DC Milliamperes	(ma)	60.0	60.0	60.0
Fluegas	(ACFM)	NA	NA	NA

(continued)

TABLE 26 (continued)

Conducted 9/2/87 Time (Begin-end) Test Description		Test 1 12:00-13:30 23% Sludge	Test 2 14:35-16:28 23% Sludge	Test 3 18:10-19:40 38% Sludge
MX SCRUBBER:				
Recirc. Water Flow	(gpm)	100.0	100.0	100.0
Water Temperature	(^{o}F)	173.5	175.0	174.2
Scrubber Water pH		7.81	7.96	7.94
Scrubber Purge Water	(gpm)	6.30	9.08	7.89
ID FAN:				
Vacuum (Draft)	(in w.c.)	9.50	11.00	11.29
STACK:				
Oxygen(b)	(%)	9.30	9.80	8.40
Carbon Dioxide(b)	(%)	11.10	10.70	12.10

(a) Calculated from material balance

(b) Measured by Continuous Emissions Monitor timer, which adjusts the length of the feed cycle. At the beginning of the cycle, the weigh scale control system starts the feed conveyor belt. When the weight on the scale reaches the setpoint, the conveyor belt is stopped. The weigh scale holds the charge until the timer cycle is complete, and then it discharges the charge to the ram trough. With the large lumps of sludge of various size, the weight fed to the scale often exceeded the setpoint by a factor of two. A single large lump of material was sufficient to cause this. A cycle of the ram feeder would feed anywhere from 40 to 100 lb of this material into the kiln. After a large lump was charged, the operator would have to stop the feed for a few minutes to prevent the kiln temperature from increasing excessively due to the high BTU-content of the sludge.

Slagging --

No noticeable slagging occurred during the tests showing that sludge containing 1% Na_2SO_4 can be fed without problems.

Temperature Control --

Rotary kiln temperatures were easily maintained near the lower part of the operating range, indicating that adequate temperature control is feasible.

Particulate Emissions --

Particulate emissions remained in compliance, as shown in Table 27. These results also fit the correlation with TDS shown in Figure 13 (Section 5).

Decontamination of Byproduct Streams --

Samples of purge water, kiln ash, cyclone ash and separator sludge were analyzed for selected constituents, which are listed in Tables 28, 29, and 30. The analysis showed that the byproduct streams would just fail the stringent delisting criteria as described below.

Purge Water -- Purge water passed all requirements except for 2,3,7,8-TCDD. The failure was due to a problem related to the analysis for TCDD. The delisting requirement specified that the concentration of dioxins and furans expressed as equivalent 2,3,7,8-TCDD be below the analytical detection limit. Since this was the case, the Office of Solid Waste (OSW) also required that TCDD be not detected and that the practical quantitation limits (PQLs) be within specified values for each isomer. This is explained further in Tables 28 and 29. As shown in Table 28, although the critical dioxin and furan isomers were below the detection limits and the equivalent 2,3,7,8-TCDD was below the delisting limit, the purge water would have failed the delisting criteria based upon a failure to achieve the specified PQL. The high resolution gas chromatography/high resolution mass spectroscopy (HRGC/HRMS) achieved detection limits of 132 ppq

TABLE 27. PARTICULATE SAMPLING PARAMETERS AND EMISSION SUMMARY - BROMINATED SLUDGE TESTS

Test No.	1	2	3
Date (1987)	9/2	9/2	9/2
Sampling Times			
Start	12:00	14:35	18:10
Stop	13:30	16:20	19:40
Moisture (%) measured	50.5	51.0	51.2
Moisture (%) calculated	49.4	50.0	47.5
Dry mole fraction (100 - %M)	0.5057	0.5002	0.5249
CO_2 (% dry)	11.1	10.7	12.1
O_2 (% dry)	9.3	9.8	8.4
N_2 (% dry)	79.6	79.5	79.5
Dry MW (Lb/Lb mole)	30.15	30.10	30.27
Wet MW (Lb/Lb mole)	24.14	24.05	24.44
Excess Air (%)	79.4	87.6	66.7
Avg. Stack Temp. (°F)	176.6	177.1	176.9
Stack Gas Velocity (afpm)	1349.4	1459.6	1422.5
Stack Flow Rate (dscfm)	2170.0	2319.9	2485.9
Stack Flow Rate (wscfm)	5397.5	5838.3	5690.0
PARTICULATE EMISSIONS SUMMARY			
Grain Loading (gr/dscf)	0.0652	0.0695	0.0677
Grain Loading (gr/ascf)	0.0262	0.0276	0.0296
Loading (gr/dscf @ 12% CO_2)	0.0705	0.0779	0.0671
Loading (gr/dscf per permit)			
Emission Rate (Lb/hr)	1.2129	1.3811	1.4421

TABLE 28. ANALYSES OF RESIDUE STREAMS FOR DIOXINS AND FURANS IN BROMINATED SLUDGE TESTS

	Purge Water Prior to Test 1		Purge Water Test 1		Purge Water Test 3	
	Meas. (ppt)	Delist. (ppt)	Meas. (ppt)	Delist. (ppt)	Meas. (ppt)	Delist. (ppt)
2378 & 2378 Substituted Cogeners:						
2,3,7,8-Tetrachloro-dibenzo-p-dioxin TCDD	1.67U	0.12	0.132U	0.12	0.42U	0.12
12378-P5CDD	0.003U	--	0.001U	--	0.002U	--
123478-H6CDD	0.007U	--	0.001U	--	0.004U	--
123678-H6CDD	0.007U	--	0.001U	--	0.004U	--
123789-H6CDD	0.007U	--	0.001U	--	0.004U	--
1234678-H7CDD	0.019U	--	0.001U	--	0.010U	--
2378-Tetrachloro-dibenzofuran	0.107	--	0.003	--	0.001U	--
12378-P5CDF	0.001U	--	0.001U	--	0.001U	--
23478-P5CDF	0.001U	--	0.001U	--	0.001U	--
123478-H6CDF	0.003U	--	0.001U	--	0.002U	--
123678-H6CDF	0.003U	--	0.001U	--	0.002U	--
234678-H6CDF	0.003U	--	0.001U	--	0.002U	--
123789-H6CDF	0.003U	--	0.001U	--	0.002U	--
1234678-H7CDF	0.009U	--	0.001U	--	0.005U	--
1234789-H7CDF	0.336	--	0.001U	--	0.005U	--
Other Homologues:						
TCDDs	0.146U	--	0.001U	--	0.001U	--
PCDDs	0.003U	--	0.001U	--	0.001U	--
H6CDDs	0.007U	--	0.001U	--	0.001U	--
H7CDDs	0.019U	--	0.001U	--	0.001U	--
OCDD	0.029U	--	0.070	--	0.070	--
TCDFs	0.284	--	0.001U	--	0.001U	--
PCDFs	0.001U	--	0.001U	--	0.001U	--
H6CDFs	0.003U	--	0.001U	--	0.001U	--
H7CDFs	0.009U	--	0.001U	--	0.001U	--
OCDF	0.336	--	0.535	--	0.535	--
2,3,7,8-TCDD Equivalent	0.011	0.002	0.0003	0.002	0.00	0.002

(continued)

TABLE 28 (continued)

	Kiln Ash		Cyclone Ash		Separator Sludge	
	Test 1		Test 1		Test 1	
	Meas. (ppt)	Delist. (ppt)	Meas. (ppt)	Delist. (ppt)	Meas. (ppt)	Delist. (ppt)
2378 & 2378 Substituted Cogeners:						
2,3,7,8-Tetrachloro-dibenzo-p-dioxin TCDD	31 U	15	21 U	15	70 U	15
12378-P5CDD	1.0U	--	1.0U	--	1.0U	--
123478-H6CDD	1.0U	--	1.0U	--	1.0U	--
123678-H6CDD	1.0U	--	1.0U	--	2.0	--
123789-H6CDD	1.0U	--	1.0U	--	1.0U	--
1234678-H7CDD	1.0U	--	1.0U	--	5.0	--
2378-Tetrachloro-dibenzofuran	6.0	--	1.0U	--	445	--
12378-P5CDF	1.0U	--	1.0U	--	121	--
23478-P5CDF	4.0	--	1.0U	--	377	--
123478-H6CDF	14.0	--	1.0U	--	87	--
123678-H6CDF	1.0U	--	1.0U	--	39	--
234678-H6CDF	1.0U	--	1.0U	--	1.0U	--
123789-H6CDF	2.0	--	1.0U	--	1.0U	--
1234678-H7CDF	1.0U	--	1.0U	--	24.	--
1234789-H7CDF	1.0U	--	1.0U	--	5.0	--
Other Homologues:						
TCDDs	1.0U	--	1.0U	--	1.0U	--
PCDDs	3.0	--	1.0U	--	1.0U	--
H6CDDs	1.0U	--	1.0U	--	8.0	--
H7CDDs	1.0U	--	1.0U	--	2.0	--
OCDD	1.0U	--	1.0U	--	7.0	--
TCDFs	39	--	1.0U	--	396	--
PCDFs	33	--	1.0U	--	642	--
H6CDFs	1.0U	--	1.0U	--	155	--
H7CDFs	1.0U	--	1.0U	--	13	--
OCDF	44	--	42.	--	84	--
2,3,7,8-TCDD Equivalent	1.25	0.5	0.00	0.5	96.7	0.5

2,3,7,8 -TCDD Equivalents calculated per Table 29 must be below 0.002 ppt for water and 0.5 ppt for solids or if all homologues and cogeners are not detected. Detection limits must be below 0.12 ppt for water and 15 ppt for solids. For this reason two delisting limits are shown in the above table.

U - Not detected. The number before the U is the detection limit.

TABLE 29. POLYCHLORINATED DIOXINS/FURANS ISOMERS AND THEIR RELATIVE TOXICITY

A conservative estimate of the level of concern is a weighted sum of the concentration of tetra-, penta-, and hexachlorinated dibenzo(p)-dioxins and -dibenzofuran isomers. The weighting factors are given below, and represent current best estimates of the relative toxicities of the "2,3,7,8-substituted" congeners. In the absence of isomer-specific data, it is prudent to consider all detected isomers in a homologue to be "2,3,7,8-substituted" isomers.

CDD/CDF Isomers and Their Relative Toxicity

DIOXIN		DIBENZOFURAN	
Isomer	Relative Toxicity	Isomer	Relative Toxicity
Mono thru Tri CDDs	0		
2,3,7,8-TCDD	1	2,3,7,8-TDCFs	0.1
other TCDD	0.01	other TDCFs	0.001
2,3,7,8-Penta CDDs	0.5	2,3,7,8-Penta CDFs	0.1
other Penta CDDs	0.005	other Penta CDFs	0.001
2,3,7,8-Hexa CDDs	0.04	2,3,7,8-Hexa CDFs	0.01
other Hexa CDDs	0.0004	other Hexa CDFs	0.0001

For the residues to pass the delisting analyses, the equivalent concentration of 2, 3, 7, 8-TCDD as calculated above must be lower than 0.5 ppt in the waste solids or 0.002 ppt in the purge water or the analyses must achieve non detects at or below the practical quantitation limits (PQLs) given below.

PCDD/PCDF Homologues	Solids (ppt)	Purge Water (ppt)
Tetra and Penta - CDD/CDF	≤ 15	≤ 0.12
Hexa - CDD	≤ 37	≤ 0.30

TABLE 30. ANALYSES OF RESIDUE STREAMS FOR PCBs, VOLATILES, SEMIVOLATILES, AND METALS BROMINATED SLUDGE TESTS

	Purge Water Prior to Test 1		Purge Water Test 1		Purge Water Test 3	
	Meas. (ppb)	Delist. (ppb)	Meas. (ppb)	Delist. (ppb)	Meas. (ppm)	Delist. (ppm)
PCBs as AROCHLORS:		0.10		0.10		0.10
AROCHLOR 1221	NA	--	NA	--	NA	--
AROCHLOR 1232	NA	--	NA	--	NA	--
AROCHLOR 1016 or 1242	NA	--	NA	--	NA	--
AROCHLOR 1248	NA	--	NA	--	NA	--
AROCHLOR 1254	NA	--	NA	--	NA	--
AROCHLOR 1260	NA	--	NA	--	NA	--
VOLATILES:						
Chloroform	12U	6.0	12U	6.0	12U	6.0
1,2-Dichloroethane	5U	5.0	5U	5.0	5U	5.09
Methylene Chloride	10U	680.0	I	680.0	I	680.0
Toluene	5U	0.013%	5U	0.013%	5U	0.013%
Trichloroethylene	5U	40.0	5U	40.0	5U	40.0
SEMIVOLATILES:						
Benz(a)anthracene	20U	0.1	20U	0.1	20U	0.1
Benz(b)fluoranthene	10U	0.2	10U	0.2	10U	0.2
Benzo(a)pyrene	10U	0.04	10U	0.04	10U	0.04
Chrysene	10U	2.0	10U	2.0	10U	2.0
Dibenz(a,h)anthracene	10U	0.009	10U	0.009	10U	0.009
Indeno(1,2,3-c,d)pyrene	10U	2.0	10U	2.0	10U	2.0
1,2,4,5-tetrachlorobenzene	NA	130.0	NA	130.0	NA	130.0
2,3,4,6-tetrachlorophenol	NA	4300.0	NA	4300.0	NA	4300.0
2,4,5-trichlorophenol	50U	43000.0	50U	43000.0	50U	43000.0
2,4,6-trichlorophenol	10U	20.0	10U	20.0	10U	20.0
EP TOXICITY METALS, NICKEL & CYANIDE:						
Arsenic	100U	610.	100U	610.	100U	610.
Chromium	56.	610.	10U	610.	10U	610.
Lead	50U	610.	50U	610.	50U	610.
Silver	10U	610.	10U	610.	10U	610.
Barium	35.	12000.	160	12000.	62	12000.
Cadmium	22.	100.	5U	100.	5U	100.
Selenium	50U	100.	50U	100.	50U	100.
Mercury	0.109	20.	0.10U	20.	0.10U	20.
Nickel	20U	4300.	20U	4300.	20U	4300.
Cyanide	10U	2400.	20.	2400.	20.	2400.

(continued)

TABLE 30 (continued)

	Kiln Ash		Cyclone Ash		Separator Sludge	
	Test 1		Test 1		Test 1	
	Meas. (ppb)	Delist. (ppb)	Meas. (ppb)	Delist. (ppb)	Meas. (ppm)	Delist. (ppm)
PCBs as AROCHLORS:		0.03		0.03		0.03
AROCHLOR 1221	0.050U	--	0.050U	--	0.050U	--
AROCHLOR 1232	0.025U	--	0.025U	--	0.025U	--
AROCHLOR 1016 or 1242	0.075U	--	0.075U	--	0.075U	--
AROCHLOR 1248	0.075U	--	0.075U	--	0.075U	--
AROCHLOR 1254	0.075U	--	0.075U	--	0.200	--
AROCHLOR 1260	0.046	--	0.025U	--	0.078	--
VOLATILES:						
Chloroform	0.042	0.01	0.010U	0.01	0.010U	0.01
1,2-Dichloroethane	0.010U	0.009	0.010U	0.009	0.010U	0.00
Methylene Chloride	0.100U	9.1	0.100U	9.1	0.100U	9.1
Toluene	0.050U	15%	0.050U	15%	0.050U	15%
Trichloroethylene	0.10U	0.66	0.10U	0.66	0.10U	0.66
SEMIVOLATILES:						
Benzo(a)anthracene	0.330U	0.1	0.330U	0.1	0.330U	0.1
Benzo(b)fluoranthene	0.330U	0.18	0.330U	0.18	0.330U	0.18
Benzo(a)pyrene	0.330U	0.04	0.330U	0.04	0.330U	0.04
Chrysene	0.330U	17.0	0.330U	17.0	0.330U	17.0
Dibenzo(a,h)anthracene	0.330U	0.008	0.330U	0.008	0.330U	0.008
Indeno(1,2,3-c,d)pyrene	0.330U	33.0	0.330U	33.0	0.330U	33.0
1,2,4,5-tetrachlorobenzene	NA	72.0	NA	72.0	NA	72.0
2,3,4,6-tetrachlorophenol	NA	710.0	NA	710.0	NA	710.0
2,4,5-trichlorophenol	1.600U	0.13	1.600U	0.13	1.600U	0.13
2,4,6-trichlorophenol	0.330U	0.34	0.330U	0.34	0.330U	0.34
EP TOXICITY METALS, NICKEL & CYANIDE:						
Arsenic	0.100U	0.33	0.100U	0.33	0.100U	0.33
Chromium	0.029	0.33	0.800	0.33	0.470	0.33
Lead	0.060	0.33	0.050U	0.33	1.90	0.33
Silver	0.010U	0.33	0.010U	0.33	0.010U	0.33
Barium	0.17	6.60	0.140	6.60	0.560	6.60
Cadmium	0.018	0.70	0.005U	0.70	1.0	0.70
Selenium	0.050U	0.70	0.050U	0.70	0.050U	0.70
Mercury	0.0001U	0.01	0.0001U	0.01	0.002	0.01
Nickel	0.027	2.30	0.020U	2.30	1.2	2.30
Cyanide	0.020	1.30	0.010U..	1.30	0.010U	1.30

U - Not detected. The number before the U is the detection limit.

NA - Not applicable

and 417 ppq for 2,3,7,8-TCDD, whereas OSW requires a PQL of 120 ppq for water.

Kiln Ash -- The 1.25 ppt of equivalent 2,3,7,8-TCDD detected in kiln ash slightly exceeded the delisting requirement of 0.5 ppt as shown in Table 28. The 42 ppb of chloroform detected in the ash slightly exceeded the 10 ppb delisting limit. The 46 ppb of PCBs detected in the ash also exceeded the 1 ppb delisting limit. Other volatile and semivolatile organics as well as metals either were not detected or they were detected at concentrations below the delisting criteria for the kiln ash.

Cyclone Ash -- The same analytical problem for 2,3,7,8-TCDD occurred with the cyclone ash as with the purge water. The cyclone ash failed delisting for 2,3,7,8-TCDD because the 21 ppt detection limit exceeded the 15 ppt PQL specified by OSW. All other organic compounds and metals either were not detected or they were detected at concentrations below the delisting criteria for the cyclone ash. However, the 800 ppb of chromium slightly exceeded the 610 ppb delisting requirement.

Separator Sludge -- The 96.7 ppt of equivalent 2,3,7,8-TCDD exceeded the 0.5 ppt delisting limit. All other organic compounds and metals either were not detected or were detected at concentrations below the delisting limits. Small quantities of separator sludge can be recycled without adversely affecting the process economics.

Ambient Air Quality --

Three ambient air monitors were placed inside the incinerator building in the vicinity of the rotary kiln. One monitor was located at the feed end of the kiln at the front face plate. The second monitor was located about ten feet from the side of the kiln, and the third monitor was located about three feet above the ash discharge area of the kiln.

As shown in Table 31, concentrations of organic halides, hydrogen chloride, and hydrogen bromide were well below the Threshold Limit Values (TLVs) for worker exposure. Although hydrogen fluoride was analyzed as slightly exceeding the TLV in the discharge area, this reading was high because the method blank sample showed comparable concentrations. Measured concentrations were highest at the ash discharge area of the kiln. This correlates with observations of several smoking barrels of ash during the three tests. Eight out of the last twenty-four barrels of kiln ash had visible smoke.

Acid Gas Removal --

Although the measured efficiency for removal of hydrogen bromide gas was less than 99%, total emissions were less than the 4 lb/hr specified by the permit. Hence, acid gas removal was adequate, as shown in Table 32.

TABLE 31. RESULTS OF AMBIENT AIR MONITORING

	Test 1	Test 2	Test 3
Total Organic Halides (wppb)			
Location 1	<4.88	<6.07	<6.24
Location 2	1.07	1.42	1.30
Location 3	<6.69	<10.36	<9.35
Total Bromides as HBr (vppm) TLV = 3 vppm			
Location 1	0.0419	<0.0434	0.0447
Location 2	0.0407	0.0535	0.1391
Location 3	0.395	0.712	0.401
Total Chlorides as HCl (vppm) TLV = 5 vppm			
Location 1	<0.0776	<0.0964	<0.0993
Location 2	0.0387	0.273	<0.0671
Location 3	<0.1327	<0.1645	0.416
Total Fluorides as HF (vppm) TLV = 3 vppm			
Location 1	1.53	1.86	1.92
Location 2	0.471	0.563	1.175
Location 3	2.91	3.60	3.03

Notes:

Location 1	Located about 15 feet from side of the rotary kiln.
Location 2	Located at the feed end of the rotary kiln.
Location 3	Located at the discharge end of the rotary kiln above the ash barrel.

The level of fluorides detected in the blank sample was comparable to the values listed above for both the first analysis and reanalysis of the blank. Bromides were detected in the first analysis of the blank sample but were not detected upon reanalysis of the blank. Chlorides were not detected in the first analysis of the blank sample but were detected upon reanalysis of the blank.

TLV = Threshold Limit Value - Maximum allowed concentration expressed as an 8-hour time-weighted average.

TABLE 32. ACID GAS REMOVAL FOR BROMINATED SLUDGE TESTS

	Test 1	Test 2	Test 3
Total organic halides in feed (lb/lb)	0.001044	0.001044	0.001220
Total feed rate (lb/hr)	3925	3601	4278
Total organic halide feed rate (lb/hr)	4.10	3.76	5.22
Total Inorganic Halides in stack (lb/hr)	0.0744	0.138	0.248
Removal Efficiency (%)	98.2	96.3	95.6

Test Conditions in 1988

Based upon the results from the 1987 tests, the kiln rpm was decreased to increase the residence time of the solids, and a series of seven tests were conducted in April and May 1988. The first six tests consisted of two tests with sludge, two tests with a blend of sludge, soil, and Na_2SO_4, one test with a blend of sludge and soil, and one test with a blend of sludge and ash. The seventh test, a repeat of the most successful of the first six tests, was performed with sludge. Test conditions are presented in Table 33.

Brominated Sludge Test Results in 1988

The 1988 tests showed that pure brominated sludge could be processed at rates up to 1500 lb/hr while producing delistable residues. A mixture consisting of 49.4% sludge, 45% soil, and 5.6% Na_2SO_4 prepared for test 4 caused slagging in the kiln. Due to this risk of slagging, further processing of Na_2SO_4 was discontinued. The other blends of sludge with soil or ash also were successfully processed but the sludge throughput was lower than with the pure sludge. Hence, processing of pure sludge produced the best performance.

Feed Rate --

As shown in Table 33, maximum sludge throughputs were achieved with neat sludge. During test 2 an average feed rate of 1500 lb/hr was achieved with a maximum 2278 lb/hr feed rate demonstrated during a 15-min period. Since a blend of 69% sludge and 31% soil achieved an average rate of 1410 lb/hr with a maximum 1738 lb/hr during a 15-min period, the tests showed that maximum processing rates were obtained with neat sludge.

Temperature Control --

Rotary kiln temperatures were maintained below the high temperature cut-off. This required operator intervention to stop feed during temperature transients caused by the high BTU-content of the sludge.

Decontamination of Byproduct Streams --

Samples of purge water and composite samples of kiln and cyclone ash from tests 1, 2, 6, and 7 were analyzed for the delisting constituents, which are listed in Tables 34, 35, 36, and 37. The analyses showed that the residue streams would meet the delisting criteria for organic compounds but occasionally fail the criteria for heavy metals as described below.

Purge Water -- Purge water passed all delisting criteria for organic compounds with two exceptions. The 84 ppb chloroform slightly exceeded the delisting criteria during test 7. The dioxin and furans were well above the 2 ppq

TABLE 33. BROMINATED SLUDGE AVERAGE PROCESS
OPERATING CONDITIONS - 1988 TESTS

Date	4/28/88	4/28/88	4/29/88	4/29/88	4/30/88	4/30/88	5/1/88
Test Number	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Time (Begin-End)	16:00-18:00	20:00-22:00	13:00-15:00	20:00	12:00-14:00	15:15-17:15	10:30-14:00
Test Description	100% Sludge	100% Sludge	38% Sludge 58.1% Soil 2.9% Na_2SO_4	49.4% Sludge 45% Soil 5.6% Na_2SO_4	69% Sludge 31% Soil	66% Sludge 33% Ash	100% Sludge
Combustion efficiency (%)	99.98	99.98	99.99	--	99.99	99.99	99.99
KILN:							
Combustion temperature (^oF)	1616	1608	1600	1735	1608	1633	1760
Solid waste feed rate (lb/hr)	1025	1500	2002	916	2044	1968	1357
Avg. sludge feed rate (lb/hr)	1025	1500	765	452	1410	1299	1357
Max. sludge feed rate (lb/hr)	1239	2278	1025	--	1738	1548	1846
Min. sludge feed rate (lb/hr)	797	1019	527	--	1091	464	362
Fuel to oxygen burner (lb/hr)	36.9	30.7	114.8	226.5	36.2	42.8	29.7
Oxygen flow rate (kscfh)	4.66	1.43	7.57	12.56	4.16	1.54	1.06
Vacuum (draft) (in w.c.)	0.58	1.50	0.85	0.70	0.67	0.89	0.37
Oxygen (%)	11.63	11.57	8.45	--	8.30	9.07	13.79
rpm	1.00	1.00	1.20	1.40	0.80	1.20	0.60
SCC:							
Combustion temperature (^oF)	2129	2111	2126	2140	2173	2150	2113
Combustion air flow (scfm)	1544	1689	1202	1100	1486	1533	1860
Fuel flow (lb/hr)	42.9	45.8	37.5	32.0	42.6	42.4	45.8
Vacuum (draft) (in w.c.)	2.63	4.31	3.55	3.6	3.61	4.23	7.78
Quench water recirc. flow (gpm)	54	54	54	55	54	54	54
Quench water pH	8.72	9.44	9.09	10	9.22	9.44	--
Gas exit temperature (^oF)	195.4	195.0	200.0	200.0	206.3	202.2	204.9
Oxygen GC (%)	7.96	--	9.85	7.56	6.69	6.27	6.88
Oxygen polarographic (%)	7.10	4.86	9.01	5.99	4.97	4.52	5.48
Carbon dioxide GC (%)	13.71	--	14.10	13.06	14.88	13.67	13.02
Carbon monoxide IR (ppm)	14.11	11.99	12.96	--	10.10	6.11	4.29
Total hydrocarbons GC (ppm)	2.70	--	3.95	0.85	1.83	1.44	1.38
Nitrogen dioxide (ppm)	190.1	--	276	124	212	136	156
SCC Residence time (a) (sec)	2.81	2.47	3.14	--	2.68	2.64	2.27

(continued)

TABLE 33 (continued)

Date	4/28/88	4/28/88	4/29/88	4/29/88	4/30/88	4/30/88	5/1/88
Test Number	Test 1	Test 2	Test 3	Test 4(b)	Test 5	Test 6	Test 7
Time (Begin-End)	16:00-18:00	18:00-20:00	13:00-15:00	20:00	12:00-14:00	15:15-17:15	10:30-14:00
Test Description	100% Sludge	100% Sludge	38% Sludge 58.1% Soil 2.9% Na_2SO_4	49.4% Sludge 45% Soil 5.6% Na_2SO_4	69% Sludge 31% Soil	66% Sludge 33% Ash	100% Sludge
WEP:							
AC voltage (V)	--	--	--	--	--	--	--
AC amperes (a)	--	--	--	--	--	--	--
DC voltage (KV)	8	8	8	8	8	8	8
DC milliamperes (ma)	--	--	--	--	--	--	--
Fluegas (ACFM)	4796	5464	4302	--	5032	5107	5937
MX SCRUBBER:							
Recirc. water flow (gpm)	110.7	110.7	116.5	120	120	120	114.0
Water temperature (^{O}F)	174.4	175.1	174.6	174	174.4	173.1	173.6
Scrubber water pH	8.06	9.06	8.23	9.0	7.94	8.06	--
Scrubber purge water (gpm)	1.97	5.42	4.97	--	2.67	4.00	3.33
ID FAN:							
Vacuum (draft) (in w.c.)	10.0	16.7	10.6	10	11.50	14.0	22.3
STACK:							
Oxygen GC (%)	9.31	8.63	11.75	8.69	9.76	8.20	9.34
Carbon dioxide GC (%)	12.39	11.41	11.94	12.57	12.14	12.11	11.08
Carbon monoxide GC (ppm)	2.29	1.86	2.01	0.0	3.29	2.80	1.88
Total hydrocarbons GC (ppm)	2.92	2.18	3.29	2.92	2.32	2.58	2.64
Nitrogen dioxide (ppm)	142	79	214	124	160	119	135

(a) Calculated from material balance.

(b) This mixture slagged in the kiln, data is from operator log sheets. Test 4 was not run, due to slagging.

TABLE 34. RESULTS OF SYNTEX BROMINATED SLUDGE 1988 TESTS - ANALYSES FOR TCDD/TCDF IN PURGE WATER BEFORE FILTERS

Analyte	Detection Limit (ppt)	Pretest (ppt)	Test 1 (ppt)	Test 2 (ppt)	Test 6 (ppt)	Test 7 (ppt)
2378 & 2378 Substituted Congeners:						
2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)		4.545	1.504	0.058	0.589	0.806
1,2,3,7,8-P5CDD	0.030	ND	ND	ND	ND	ND
1,2,3,4,7,8-H6CDD	0.037	ND	ND	ND	ND	ND
1,2,3,6,7,8-H6CDD	0.037	ND	ND	ND	ND	ND
1,2,3,7,8,9-H6CDD	0.045	ND	ND	ND	ND	ND
1,2,3,4,6,7,8-H7CDD	0.055	0.066	ND	ND	0.072	ND
OCDD	0.060	0.573	0.324	ND	0.837	0.350
2,3,7,8-Tetrachlorodibenzofuran	0.020	0.708	0.243	ND	0.096	0.126
1,2,3,7,8-P5CDF	0.022	0.212	0.080	ND	ND	ND
2,3,4,7,8-P5CDF	0.137	1.030	0.310	ND	0.105	ND
1,2,3,4,7,8-H6CDF	0.022	0.340	0.103	ND	0.030	ND
1,2,3,6,7,8-H6CDF	0.020	0.072	0.028	ND	ND	ND
2,3,6,7,8,9-H6CDF	0.025	0.256	0.061	ND	ND	ND
1,2,3,7,8,9-H6CDF	0.033	ND	ND	ND	ND	ND
1,2,3,4,6,7,8-H7CDF	0.030	0.076	0.038	ND	ND	ND
1,2,3,4,7,8,9-H7CDF	0.043	ND	ND	ND	ND	ND
OCDF	0.070	0.055	ND	ND	ND	ND
Other Homologues:						
TCDDs	--	0.032	ND	ND	ND	ND
PCDDs	0.193	ND	ND	ND	ND	ND
H6CDDs	0.985	ND	ND	ND	ND	ND
H7CDDs	0.055	ND	ND	ND	ND	ND
TCDFs	0.020	3.658	1.435	ND	0.393	0.170
PCDFs	0.020	2.417	0.824	ND	0.233	0.211
H6CDF	0.025	0.585	0.150	ND	0.036	ND
H7CDF	0.035	0.040	0.007	ND	0.016	ND
2,3,7,8-TCDD Equivalent		4.753	1.571	0.058	0.610	0.819

2,3,7,8-TCDD Equivalent calculated per Table 29 must be below 0.002 ppt for water or if all homologues and congeners are not detected, detection limits must be below 0.12 ppt for water.

TABLE 35. RESULT OF SYNTEX BROMINATED SLUDGE 1988 TESTS - ANALYSES FOR PCBs, VOLATILES, SEMIVOLATILES, METALS, MERCURY, AND CYANIDE IN PURGE WATER BEFORE FILTERS

Analyte	Delisting Criteria (ppb)	Detection Limit (ppb)	Pretest (ppb)	Test 1 (ppb)	Test 2 (ppb)	Test 6 (ppb)	Test 7 (ppb)
PCBs (Aroclors):							
1016, 1221, 1232, 1242, 1248,1254, and 1260	< 0.10	0.10	ND	ND	ND	ND	ND
Volatiles:							
Chloroform (Trichloromethane)	< 70	5	ND/ND	ND/ND	ND/ND	35/8	78*/84*
1,2-Dichloroethane	< 60	5	ND/ND	ND/ND	ND/ND	ND/ND	ND/ND
Methylene Chloride (Dichloromethane)	< 60	5	ND/ND	ND/ND	ND/ND	7B/ND	4BJ/ND
Toluene	<120000	5	ND/ND	ND/ND	ND/ND	ND/ND	3J/ND
Trichloroethylene	< 40	5	ND/ND	ND/ND	ND/ND	ND/ND	ND/ND
Semivolatiles:							
Benzo(a)anthracene	< 0.100	10	ND	ND	ND	ND	ND
Benzo(b)fluoranthene	< 0.200	10	ND	ND	ND	ND	ND
Benzo(a)pyrene	< 0.040	10	ND	ND	ND	ND	ND
Chrysene	< 2.0	10	ND	ND	ND	ND	ND
Dibenzo(a,h)anthracene	< 0.009	10	ND	ND	ND	ND	ND
Indeno(1,2,3-cd)pyrene	< 2.0	10	ND	ND	ND	ND	ND
1,2,4,5-Tetrachlorobenzene	< 130	50	ND	ND	ND	ND	ND
2,4,5-Trichlorophenol	< 49000	10	ND	ND	5J	ND	ND
2,4,6-Trichlorophenol	< 20.0	10	ND	ND	ND	ND	ND
2,3,4,6-Tetrachlorophenol	< 12000	--	--	--	--	--	--
Metals, Mercury, Cyanide							
Arsenic	< 610	47	131	55	110	128	155
Barium	< 12000	3	210	58	200	49	32
Cadmium	< 120	5	530*	13	1410*	31	19
Chromium	< 610	10	732*	146	367	538	262

(continued)

TABLE 35 (continued)

Analyte	Delisting Criteria (ppb)	Detection Limit (ppb)	Pretest (ppb)	Test 1 (ppb)	Test 2 (ppb)	Test 6 (ppb)	Test 7 (ppb)
Lead	< 610	36	1060*	76	440	304	327
Nickel	< 6100	21	516	9	329	75	64
Selenium	< 120	30	50	ND	100	118	135*
Silver	< 610	3	49	13	65	58	34
Mercury	< 20	0.2	2.7	ND	0.4	ND	ND
Cyanide	< 2.4	--	--	--	--	--	--

B - Detected in blank
J - Estimated, below detection limit
* - Exceeds delisting criteria
ND - Not detected

When the delisting criteria is below the detection limit, a not detected is required.

TABLE 36. RESULTS OF SYNTEX BROMINATED SLUDGE
1988 TESTS - ANALYSES FOR TCDD/TCDF
KILN AND CYCLONE ASH COMPOSITE

Analyte	Detection Limit (ppt)	Test 1 (ppt)	Test 2 (ppt)	Test 6 (ppt)	Test 7 (ppt)
2378 & 2378 Substituted Congeners:					
2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)	3	ND	ND	ND	ND
1,2,3,7,8-P5CDD	8	ND	ND	ND	ND
1,2,3,4,7,8-H6CDD	8	ND	ND	ND	ND
1,2,3,6,7,8-H6CDD	8	ND	ND	ND	ND
1,2,3,7,8,9-H6CDD	10	ND	ND	ND	ND
1,2,3,4,6,7,8-H7CDD	18	ND	ND	ND	ND
OCDD	43	ND	16J	ND	ND
2,3,7,8-Tetrachlorodibenzofuran	3	ND	ND	ND	ND
1,2,3,7,8-P5CDF	5	ND	ND	ND	ND
2,3,4,7,8-P5CDF	5	ND	ND	ND	ND
1,2,3,4,7,8-H6CDF	5	ND	ND	ND	ND
1,2,3,6,7,8-H6CDF	5	ND	ND	ND	ND
2,3,6,7,8,9-H6CDF	8	ND	ND	ND	ND
1,2,3,7,8,9-H6CDF	10	ND	ND	ND	ND
1,2,3,4,6,7,8-H7CDF	10	ND	ND	ND	ND
1,2,3,4,7,8,9-H7CDF	13	ND	ND	ND	ND
OCDF	35	ND	ND	ND	ND
Other Homologues:					
TCDDs	23	ND	ND	ND	ND
PCDDs	15	ND	ND	ND	ND
H6CDDs	79	ND	ND	ND	ND
H7CDDs	18	ND	ND	ND	ND
TCDFs	3	ND	ND	ND	ND
PCDFs	17	ND	ND	ND	ND
H6CDF	5	ND	ND	ND	ND
H7CDF	10	ND	ND	ND	ND
2,3,7,8-TCDD Equivalent		0	0	0	0

2,3,7,8-TCDD Equivalent calculated per Table 29 must be below 5 ppt for the ash.

ND - Not detected

TABLE 37. RESULTS OF SYNTEX BROMINATED SLUDGE 1988 TESTS - ANALYSES FOR PCBs, VOLATILES, SEMIVOLATILES, METALS, MERCURY, AND CYANIDE IN KILN AND CYCLONE ASH COMPOSITE

Analyte	Delisting Criteria (ppb)	Detection Limit (ppb)	Test 1 (ppb)	Test 2 (ppb)	Test 6 (ppb)	Test 7 (ppb)
PCBs (Aroclors):						
1016, 1221, 1232, 1242, 1248,1254, and 1260	< 0.10	0.10	ND	ND	ND	ND
Volatiles:						
Chloroform (Trichloromethane)	< 5400	5	ND/ND	ND/ND	ND/ND	15/9
1,2-Dichloroethane	< 4100	5	ND/ND	ND/ND	ND/ND	83/50
Methylene Chloride (Dichloromethane)	< 2400	5	17/ND	170/38	12B/4B	95B/72B
Toluene	NA	5	ND/ND	60/55	ND/ND	197/191
Trichloroethylene	< 6600	5	ND/ND	ND/ND	ND/ND	ND/ND
Semivolatiles:						
Benzo(a)anthracene	< 1100	330	ND	ND	ND	ND
Benzo(b)fluoranthene	< 1800	330	ND	ND	ND	ND
Benzo(a)pyrene	< 430	330	ND	ND	ND	ND
Chrysene	<170000	330	ND	ND	ND	ND
Dibenzo(a,h)anthracene	< 83	330	ND	ND	ND	ND
Indeno(1,2,3-cd)pyrene	<330000	330	ND	ND	ND	ND
1,2,4,5-Tetrachlorobenzene	<720000	330	ND	ND	ND	ND
2,4,5-Trichlorophenol	NA	330	ND	ND	ND	ND
2,4,6-Trichlorophenol	< 3900	330	ND	ND	ND	ND
2,3,4,6-Tetrachlorophenol	NA	330	--	--	--	--
Metals, Mercury, Cyanide						
Arsenic	< 1600	47	336	370	408	411
Barium	< 3200	3	168	690	1260	1200
Cadmium	< 320	5	11	10	12	14
Chromium	< 1600	10	10300*	113	569	471

(continued)

TABLE 37 (continued)

Analyte	Delisting Criteria (ppb)	Detection Limit (ppb)	Test 1 (ppb)	Test 2 (ppb)	Test 6 (ppb)	Test 7 (ppb)
Lead	< 1600	36	253	222	335	388
Nickel	< 6100	21	92	32	51	60
Selenium	< 320	30	141	124	215	250
Silver	< 1600	3	15	14	29	40
Mercury	< 20	0.1	ND	ND	ND	0.17
Cyanide	< 6500	250	ND	ND	1600	580

B - Detected in blank
* - Exceeds delisting criteria
ND - Not detected
NA - Not applicable

level, ranging between 58 and 1571 ppq. All other organic compounds were either not detected or were present in concentrations below the delisting criteria. Since a filter train, consisting of a sand filter and two carbon beds connected in series, was to be used on the purge water during regular operations to meet the stringent delisting criteria, the low levels of dioxins and furans were not considered to be a problem. Subsequent delisting tests, on the sludge conducted in September 1988, demonstrated that this hypothesis was true.

Composite of Kiln Ash and Cyclone Ash -- Since the delisting rules [19] permitted compositing the kiln and cyclone ash, analyses for the required analytes were performed on composite samples. Decontamination of the ash residue was excellent. Most of the organic compounds were not detected or were found in concentrations that were very much below the delisting limits, as shown in Tables 36 and 37. Separator sludge was not analyzed since it was recycled during the testing and it was to be recycled during regular operations.

The composite sample from test 1 exceeded the delisting limit for chromium, and since the chromium could potentially prevent the solid residues from being delisted, stabilization tests were conducted on the ash. Samples from test 1 were stabilized with 15% portland cement and 75% portland cement [20]. As shown in Figure 21, maximum chromium concentrations in the leachate from the multiple extraction procedure (test procedure required for stabilized solids in the delisting rule) meet the delisting criteria when the residue is stabilized with approximately 60% portland cement.

Ambient Air Monitoring --

During the 1988 tests, monitoring was conducted in a real time method by using Draeger tube samples for bromine (Br_2) and chlorine (Cl_2), the acid gases hydrogen bromide (HBr) and hydrogen chloride (HCl), and methyl bromide (CH_3Br). Measurements were taken inside ash collection barrels since the previous tests had shown that the barrels were the source of these emissions. As shown in Table 38, most measurements yielded nondetects or values below the eight-hour exposure limits (TLVs). Two measurements taken inside closed smoking barrels during test 3 had HCl/HBr levels slightly above the TLV but, a measurement taken at the ash operator's station at this time was nondetect. One measurement during test 7 taken above a smoking ash barrel also slightly exceeded the TLV for HCl/HBr. Based upon these results, time-weighted concentrations in the building and at the ash operator station were well within recommended worker exposure limits.

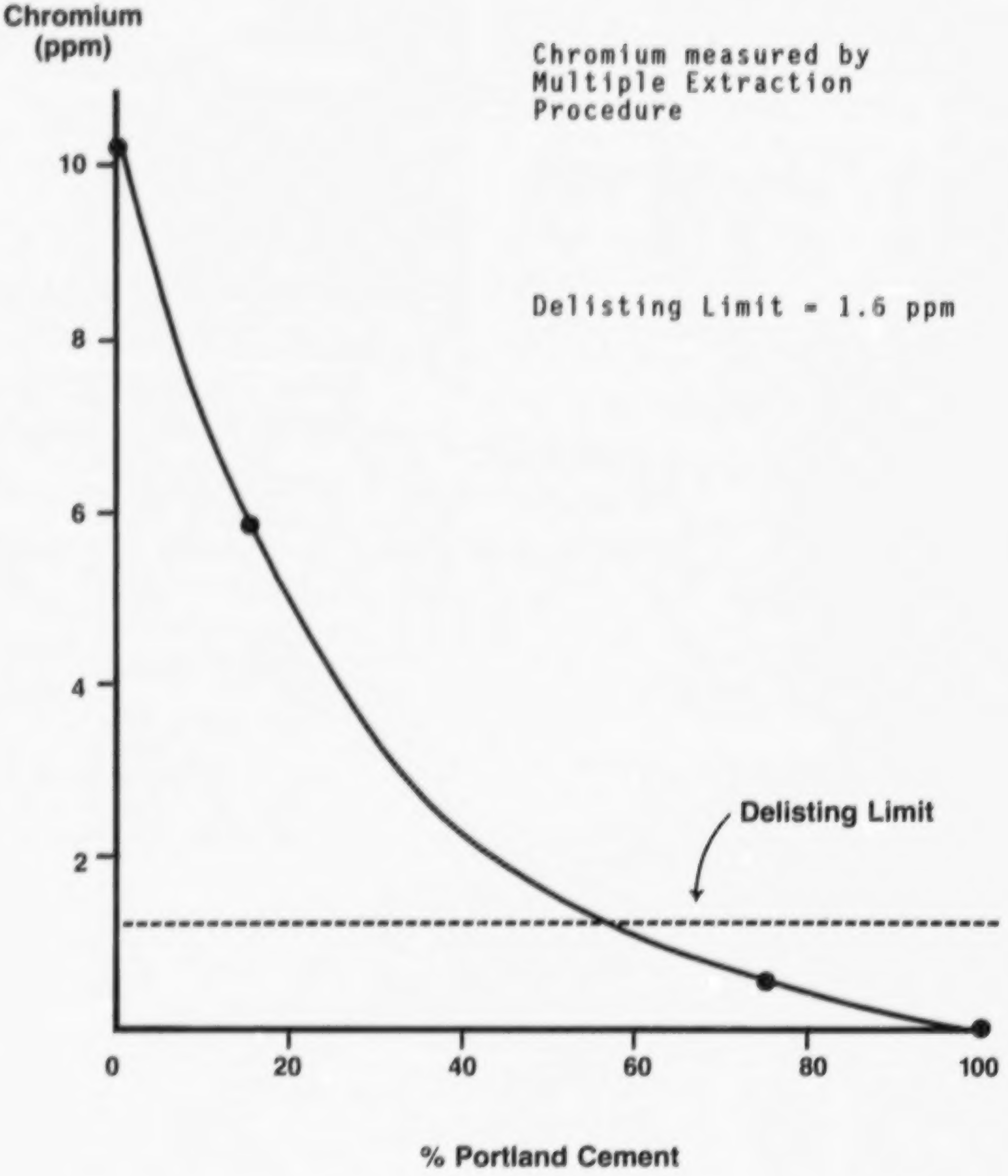


Figure 21. Effect of portland cement on leachability of ash from brominated sludge.

TABLE 38. RESULTS OF 1988 AIR MONITORING BROMINATED SLUDGE SCOPING BURN

Date	Test	Location	Component	Concentration	(vppm)
			Cl_2/Br_2	HBr/HCl	CH_3Br
		TLV (vppm) =	0.5 0.1	3.0 5.0	20.0
4/28/88	1 prerun	Kiln ash drum	ND	--	--
	prerun	Kiln ash drum	--	ND	--
	prerun	Kiln ash drum	--	--	ND
4/28/88	1	Kiln ash drum	ND	--	--
		Kiln ash drum	--	ND	--
		Kiln ash drum	--	--	ND
4/28/88	2 prerun	Kiln ash drum	--	ND	--
	prerun	Kiln ash drum	--	--	--
4/28/88	2	Kiln ash drum	ND	--	--
		Kiln ash drum	--	ND	--
		Kiln ash drum	--	--	3
4/29/88	3 prerun	Kiln ash drum	--	6	--
4/29/88	3	Kiln ash drum[1]	--	4	--
		Kiln ash drum[1]	--	25	--
		Ash operator's station	--	ND	--
		Kiln ash drum	--	--	3
4/30/88	5	Kiln ash drum	--	3.0	--
		Kiln ash drum	--	1.5	--
		Kiln ash drum	--	--	ND
		Kiln ash drum	ND	--	--
4/30/88	6	Kiln ash drum	--	1.0	--
		Kiln ash drum	--	1.0	--
5/1/88	7	Kiln ash drum	--	6.0	--
		Cyclone ash	--	ND	--
		Kiln ash drum	ND	--	--
		Ash operator station	ND	--	--
		Ash operator station	--	2.0	--

Notes:

1. Data taken inside hot drum with lid on.
2. Run 3 data at ash operator's station taken immediately after high reading inside ash drum.
3. All data from Draeger Tubes.
4. Run 4 was canceled.
5. TLV Threshold Limit Value

FATE OF HEAVY METALS

Because the brominated sludge contained high concentrations of chromium, there was a concern that the emissions of heavy metals from the stack could produce a significant health risk during the incineration of the material. To address this concern stack testing for heavy metals was conducted concurrently with the delisting tests in September, 1988. The metal emissions of concern, measured by the stack tests, were arsenic (As), cadmium (Cd), hexavalent chromium (Cr^{+6}), total chromium (Cr), lead (Pb) and mercury (Hg). Beryllium, antimony, barium, silver and thallium were not measured because their occurrence is rare. The results of the stack testing were compared with the Tier II emission rates given in the draft version of EPA's proposed incinerator amendments [21]. The Tier II emission rates are conservative screening limits, which insure that the maximum increased cancer risks do not exceed 1×10^{-5} for the aggregate of the heavy metals emissions. The results of the two stack tests showed that the metals emissions from the MIS complied with the proposed incinerator amendments.

The stack testing also provided the opportunity to explore the fate of the heavy metals as they were partitioned to the various residue streams generated by the MIS as follows. Concentrations of the metals of concern were measured in the waste feed, kiln ash, cyclone ash, separator sludge and process water. Mass balances were performed for each metal species to supplement concentration data. The behavior of lead was examined by analyzing its occurrence in various particle size ranges for the kiln ash, cyclone ash, and separator sludge. The results showed that Pb, Hg and Cd were depleted in the kiln and cyclone ash and were enriched in the separator sludge and stack particulates and that Cr^{+6} occurred only in the cyclone ash. The data and the conclusions derived from the data are discussed in greater detail below.

MIS Operating Conditions

Process operating conditions for the heavy metals tests, which were run concurrently with test 2 and test 4 of the delisting tests, are summarized in Table 39. As shown in the table, operating conditions were consistent for the two tests. The sludge was fed at 1630 lb/hr, with about a 1700°F average kiln temperature, a 2100°F SCC temperature, a 175°F stack gas temperature, a 6.25% (wet) excess kiln oxygen and a solids residence time of 27 minutes (0.8 rpm).

Sampling and Analysis

The sampling and analysis procedure employed approved EPA methods. Total metals was determined using "Methodology for

TABLE 39. BROMINATED SLUDGE AVERAGE PROCESS
OPERATING CONDITIONS - DELISTING TESTS

Date: 1988	9/7 - 9/8	9/8	9/8 - 9/9	9/12
Test Number	Test 1	Test 2(a)	Test 3	Test 4(b)
Time (Begin-End)	23:30-07:45	09:00-17:55	21:30-05:40	13:30-21:40
Combustion efficiency (%)	99.99	99.99	99.99	99.98
KILN:				
Combustion temperature (^{o}F)	1703	1690	1706	1720
Avg. sludge feed rate (lb/hr)	1614	1626	1639	1633
Max. sludge feed rate (lb/hr)	1961	1996	1828	1790
Min. sludge feed rate (lb/hr)	1404	1317	1130	1488
Fuel to oxygen burner (lb/hr)	42.9	77.2	42.5	66.3
Oxygen flow rate (kscfh)	5.76	3.49	5.12	5.20
Vacuum (draft) (in w.c.)	0.47	0.55	0.50	0.47
Oxygen (%)		6.08		6.58
RPM	0.80	0.80	0.80	0.80
SCC:				
Combustion temperature (^{o}F)	2100	2100	2100	2113
Combustion air flow (SCFM)	1593	1570	1680	1775
Fuel flow (lb/hr)	46.7	45.0	47.5	46.0
Vacuum (draft) (in w.c.)	7.67	7.85	8.30	6.68
Quench water recirc. flow (gpm)	NA	64	65.4	67.6
Quench water pH	NA	NA	NA	8.75
Gas exit temperature (^{o}F)	NA	178.	179.0	181.0
Oxygen by GC (%)	7.63	9.34	7.58	7.91
Oxygen by polarographic (%)	6.54	7.97	5.88	5.59
Carbon dioxide by GC (%)	14.12	12.96	13.65	13.56
Carbon monoxide by IR (ppm)	12.26	7.84	9.89	11.73
Total hydrocarbons by GC (ppm)	47.34	11.60	2.71	2.37
Nitrogen dioxide (ppm)	191.	496.	105.	85.
SCC Residence time(c) (sec)	2.19	2.51	2.31	2.59

(continued)

TABLE 39. (continued)

Date: 1988 Test Number Time (Begin-End)	9/7 - 9/8 Test 1 23:30-07:45	9/8 Test 2[1] 09:00-17:55	9/8 - 9/9 Test 3 21:30-05:40	9/12 Test 4[2] 13:30-21:40
MX SCRUBBER:				
Recirc. water flow (gpm)	NA	101.5	99.9	113.3
Water temperature (^{o}F)	NA	161.5	153.0	160.0
Scrubber water pH	NA	NA	NA	8.44
Scrubber purge water (gpm)		7.23	7.25	6.58
ID FAN:				
Vacuum (draft) (in w.c.)	NA	23.4	25.5	26.89
STACK:				
Gas Temperature (^{o}F)	NA	172.	NA	176.
Flow Rate (acfm)	NA	7000.	NA	8800.
Velocity (ft/sec)	NA	17.5	NA	22.0
Oxygen by GC (%)	13.48	13.91	12.04	11.73
Carbon dioxide by GC (%)	8.28	8.08	9.38	9.60
Carbon monoxide by GC (ppm)	NA	1.15	0.04	0.37
Total hydrocarbons by GC (ppm)	53.22	6.55	3.93	3.49
Nitrogen dioxide (ppm)	115	288	72	68

(a) Stack sampled for metals from 09:48 to 12:47.

(b) Stack sampled for metals from 19:10 to 21:41.

(c) Calculated from WEP flow measurement.

Determination of Trace Metal Emissions in Exhaust Gases from Stationary Source Combustion Processes"[21]. The hexavalent chromium was determined using the Draft Method (11/5/87) "Determination of Hexavalent Chromium Emissions from Decorative and Hard Chrome Electroplating"[22].

Sampling --

Each test used two modified EPA Method 5 trains: the first train, shown in Figure 22, was modified to sample total metals; the second train was modified to sample Cr^{+6}. The first train included: a quartz nozzle (nickle for test 2), a glass-lined probe, a Whatman QM-A filter, and an impinger train. The first impinger was empty, the second and third impingers contained 100 mL of 5% $HNO_3/10\%H_2O_2$ solution, the fourth impinger contained 100 mL acidic $KMnO_4$, the fifth impinger contained 100 mL 0.5N NaOH (not shown) and the sixth impinger contained 200g silica gel. The second train was similar to the first train but it did not use a filter, used 0.1 N NaOH in the first and second impingers during the first test. The normality of the NaOH was increased to 0.3 N for the second test. The third, fourth, and fifth impingers of the Cr^{+6} train were empty. Waste feed, kiln ash, cyclone ash, and separator sludge were sampled by compositing.

Particle Size Distributions --

Particle size distributions for kiln ash, cyclone ash and separator sludge were determined with a MicroTrac^R Model 7995 size analyzer.

CCSEM Analyses --

The presence of lead in various particle size ranges for kiln ash, cyclone ash and separator sludge was examined using Computer Controlled Scanning Electron Microscopy (CCSEM). The system used for the CCSEM evaluation consisted of a Philips Model 515 electron microscope equipped with an EDAX Model PV9900 energy dispersive x-ray spectrometer (EDS) and LeMont Scientific Model DA-10 image analyzer.

The CCSEM analysis procedure was as follows. Each sample (plus a National Bureau of Standards reference material) was first analyzed using only the EDS to determine the major elements present and their relative weight percentages. Based on the results of this evaluation, appropriate chemical categories were established in a special computer definition file. Each chemical category in the definition file included measurable concentrations (in weight percents) of one or more specific elements. For example the "Pb Containing" category included all particles containing Pb.

Stack Emissions

As discussed above, the metals testing program showed that the metal emissions were below the Tier II emissions screening

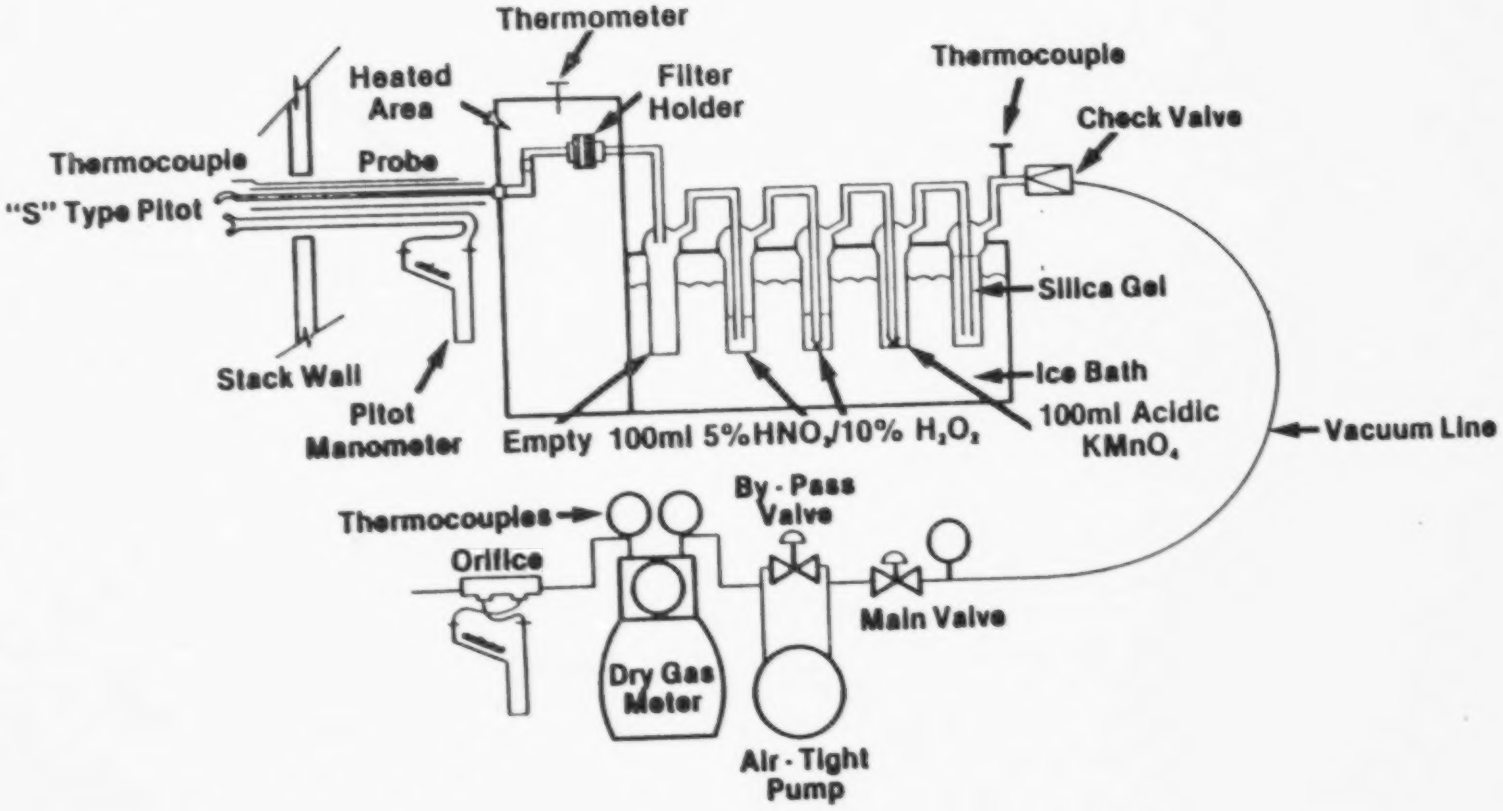

Thermometer
Heated Area
Filter Holder
Thermocouple
Check Valve
Thermocouple
Probe
"S" Type Pitot
Silica Gel
Ice Bath
Stack Wall
Pitot Manometer
Empty 100ml 5%HNO$_3$/10% H$_2$O$_2$
100ml Acidic KMnO$_4$
Vacuum Line
Thermocouples
By-Pass Valve
Orifice
Main Valve
Dry Gas Meter
Air-Tight Pump

Figure 22. Trace metals sampling train.

levels presented in the proposed amendments to the hazardous waste incinerator regulations [23]. The stack emission rates and the Tier II emissions levels are presented in Table 40. The results show that the measurement of hexavalent chromium was necessary to prove that the emission levels were acceptable. Measurement of total chromium only along with the required conservative assumption that all chromium was hexavalent chromium would have given an emission level above the proposed limit.

Although lead emissions were acceptable, they approached within 31% of the allowable levels. Since the concentration of lead in the waste material was a moderate 180 ppm, the measured emission rates show that waste materials containing high concentrations of lead could have excessive emission rates.

Metals Partitioning

Concentrations --

The results of the analyses of the different residues, which are presented in Table 41, showed that metal concentrations varied greatly. Hexavalent chromium was found in the cyclone ash and the analyses showed that about 17% to 19% of the chromium in the cyclone ash had converted to this form. However, only minor quantities of hexavalent chromium, equivalent to about 1% to 2% of the total chromium, were detected in the separator sludge. Concentrations of chromium and arsenic remained reasonably constant in the different residue streams. The metals that form low boiling point compounds, i.e. cadmium, lead and mercury, had much lower concentrations in the kiln ash and cyclone ash residues than in the waste feed. Also cadmium and lead exhibited much lower concentrations in the cyclone ash than in the kiln ash. The concentrations of cadmium and lead were about 12% to 33% lower in the kiln ash and about 1% to 2% lower in the cyclone ash than in the waste. Mercury was not detected in either the kiln ash or cyclone ash. This data is in general agreement with the equilibrium predictions for mercury and lead presented in Reference 30. However, the behavior of arsenic, which also forms low boiling point compounds, was anomalous.

As shown in Table 41, cadmium and lead concentrated in the separator sludge at levels 5 to 16 times greater than the concentrations in the waste feed. This concentrating phenomenon was even greater in the stack emissions. For example, lead concentrations were about 50 times greater in the stack than in the waste; cadmium about 65 times; and mercury about 85 to 90 times.

The above behavior is consistent with evaporation of low boiling point compounds in the hot part of the incineration system (1700°F in kiln, 2100°F in SCC) followed by

TABLE 40. METALS EMISSIONS FROM THE MIS AT THE DENNEY FARM SITE

Metal Species	Proposed Tier II Emission Limit (g/sec)	Measured Emission Rates	
		Test 1 (g/sec)	Test 2 (g/sec)
Carcinogens:			
Arsenic	1.50×10^{-4}	5.21×10^{-6}	4.41×10^{-6}
Cadmium	3.80×10^{-4}	2.01×10^{-5}	2.93×10^{-5}
Hexavalent Chromium	5.40×10^{-5}	$<1.00 \times 10^{-5}$	$<2.00 \times 10^{-5}$
Chromium	NA	8.67×10^{-5}	1.15×10^{-4}
Beryllium	2.60×10^{-4}	--------	--------
Toxics:			
Antimony	1.60×10^{-2}	--------	--------
Barium	3.20	--------	--------
Lead	5.80×10^{-3}	1.37×10^{-3}	1.83×10^{-3}
Mercury	1.10×10^{-1}	1.07×10^{-4}	1.46×10^{-4}
Silver	3.20×10^{-1}	--------	--------
Thallium	$3.20 \times 10^{+1}$	--------	--------

TABLE 41. HEAVY METAL PARTITIONING IN THE MIS FOR BROMINATED SLUDGE FEED

a). HEAVY METALS CONCENTRATIONS

Metal	Waste Feed(a) (ug/g)		Kiln Ash (ug/g)		Cyclone Ash (ug/g)		Separator Sludge(b) (ug/g)		Stack Emissions (ug/g)	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Arsenic	34.66	42.78	33.00	41.00	71.70	62.40	64.75	49.00	28.39	20.42
Cadmium	1.68	2.09	0.20	0.69	0.04	0.01	23.80	18.83	109.52	135.65
Hexavalent Chromium	<1.00	<1.00	<0.05	<0.05	211.00	271.00	17.90	16.05	<57.15	<46.64
Chromium	1463.00	1601.00	1251.00	1410.00	1219.00	1584.00	1062.00	1220.00	472.40	532.40
Lead	141.01	180.21	26.00	55.20	1.40	1.33	1670.00	837.50	7464.74	8472.59
Mercury	6.76	7.15	<0.31	<0.35	<0.29	<0.32	11.33	8.20	583.01	675.96

b). CONCENTRATION FACTORS

Metal	Waste Feed		Kiln Ash		Cyclone Ash		Separator Sludge		Stack Emissions	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Arsenic	1.00	1.00	0.95	0.96	2.07	1.46	1.87	1.15	0.82	0.48
Cadmium	1.00	1.00	0.12	0.33	0.02	0.01	14.16	9.00	65.18	64.87
Hexavalent Chromium(c)	NA	NA	NA	NA	1.00	1.00	0.08	0.06	NA	NA
Chromium	1.00	1.00	0.86	0.88	0.83	0.99	0.73	0.76	0.32	0.33
Lead	1.00	1.00	0.18	0.31	0.01	0.01	11.84	4.65	52.94	47.02
Mercury	1.00	1.00	<0.05	<0.05	<0.04	<0.04	1.67	1.15	86.20	94.59

Notes:

(a) Metal concentration in the waste feed is expressed on a dry volatile matter free basis or on the basis of ash as follows = ug metal/ug of ash.

(b) Metal concentration in separator sludge is expressed on a dry basis.

(c) All concentration factors are based upon waste feed concentration except hexavalent chromium which is based upon cyclone ash concentration.

Concentration factor = Conc. of the metal in the residue stream/Conc. of the metal in the waste feed.

condensation of the compounds in the cool part of the system (190°F) [24]. A proportionately greater mass of material condenses on the lower weight small-diameter particles due to their higher surface-to-volume ratio. As illustrated by the particle size distribution data presented in Table 42, the coarsest particles are removed at each stage of particulate removal in the MIS. Since coarse particles are removed more efficiently by the air pollution control devices than the fine particles, and fine particles contain greater amounts of condensed volatile materials, the concentration of volatile metals in the solid residue streams increases with each stage of particulate removal.

The CCSEM data, presented in Table 43, confirm this evaporation/condensation mechanism. Lead appears in the finest particle sizes (<10 u) of the kiln ash. It disappears in the cyclone ash and it reappears in the fine separator sludge particles.

The greater depletion of the volatile metals in the cyclone ash compared to the kiln ash can be explained by an evaporation mechanism as follows. Cyclone ash consists of fine particles entrained into the flue gas stream. These fine particles closely approach the temperature of the flue gas. Measurements of the flue gas temperature in the MIS by a high-velocity-shielded-thermocouple have shown that the flue gas temperature is about 200°F higher than the kiln ash temperature. This higher temperature of the cyclone ash would result in greater evaporation of volatile metal compounds.

Heavy Metals Material Balances

In general, the material balances for individual metal species had excellent closures. With the exception of mercury, closure for the individual metal species ranged from 76% to 123% of the material measured in the waste stream. Only about 27% of the mercury was accounted for. The data is valuable for estimating emissions from other incineration units with similar air pollution control equipment.

The material balances are presented in Tables 44 and 45. To aid engineering calculations and to present different perspectives, the data is presented in three ways. For each metallic species, the first row of the table presents the flow rates in g/sec of the metal in each solid residue. The second row shows the percent of the metal, retained in a particular solid residue stream relative to the total amount of metal accounted for in the residue streams. The third row shows the percent of the metal retained in a particular solid residue stream relative to the original amount of metal in the waste feed.

TABLE 42. PARTICLE SIZE DISTRIBUTIONS FOR SOLID RESIDUES FROM BROMINATED SLUDGE FEED

Particle Size Range (microns)	Kiln Ash (Vol. %)	Cyclone Ash (Vol. %)	Separator Sludge (Vol. %)
500.00-700.00	0.1		
350.00-500.00	1.3		
250.00-350.00	4.6		
176.00-250.00	6.6	0.7	
125.00-176.00	5.7	1.5	
88.00-125.00	5.9	4.7	
62.00-88.00	8.4	11.0	
44.00-62.00	9.6	16.0	
31.00-44.00	10.6	19.0	
22.00-31.00	9.9	17.5	
16.00-22.00	7.7	14.2	0.6
11.00-16.00	8.5	9.8	5.7
7.80-11.00	5.9	3.1	13.1
5.50-7.80	4.3	1.7	18.3
3.90-5.50	2.7	0.8	21.6
2.80-3.90	3.6		16.5
1.69-2.80	4.0		9.9
1.10-1.69	0.6		6.4
0.66-1.01			3.8
0.43-0.66			2.6
0.34-0.43			0.9
0.24-0.34			0.3
0.17-0.24			0.2
<0.17			0.1

TABLE 43. LEAD DISTRIBUTION IN SOLID RESIDUES AS DETERMINED BY CCSEM ANALYSES

Particle Size (microns)	Kiln Ash % Pb-Containing	Cyclone Ash % Pb-Containing	Separator Sludge %Pb-Containing
<1.00	0.06	0.00	0.40
1.00-3.16	0.94	0.00	2.39
3.16-10.00	0.21	0.00	0.00
10.00-31.62	0.00	0.00	25.54
31.62-100.00	0.00	0.00	0.00
>100.00	0.00	0.00	0.00

% Pb containing = No. of Pb containing particles/total particles x 100

TABLE 44. HEAVY METAL FLOW RATES IN RESIDUE STREAMS
TEST ONE RESULTS

Metal		Waste Feed	Kiln Ash	Cyclone Ash	Seperator Sludge	Stack Emissions	Total(a)
Arsenic	(g/sec)	2.98×10^{-3}	1.74×10^{-3}	1.68×10^{-3}	2.52×10^{-4}	5.20×10^{-6}	3.68×10^{-3}
	(% of total)(b)		47.39	45.61	6.86	0.14	100
	(% of feed)(c)		58.51	56.32	8.47	0.17	123.47
Cadmium	(g/sec)	1.44×10^{-4}	1.05×10^{-5}	9.45×10^{-7}	9.27×10^{-5}	2.00×10^{-5}	1.24×10^{-4}
	(% of total)		8.46	0.76	74.60	16.18	100
	(% of feed)		7.28	0.65	64.19	13.92	86.04
Hexavalent Chromium	(g/sec)			4.94×10^{-3}	6.97×10^{-5}	$<1.00 \times 10^{-5}$	5.02×10^{-3}
	(% of total)			98.61	1.39	<0.20	100
	(% chromium)(d)			14.94	0.21	0.03	NA
Total Chromium	(g/sec)	1.26×10^{-1}	6.61×10^{-2}	2.85×10^{-2}	4.14×10^{-3}	8.70×10^{-5}	9.88×10^{-2}
	(% of total)		66.86	28.86	4.19	0.09	100
	(% of feed)		52.55	22.69	3.29	0.07	78.60
Lead	(g/sec)	1.21×10^{-2}	1.37×10^{-3}	3.28×10^{-5}	6.50×10^{-3}	1.40×10^{-3}	9.28×10^{-3}
	(% of total)		14.80	0.35	70.09	14.76	100
	(% of feed)		11.33	0.27	53.67	11.30	76.57
Mercury	(g/sec)	5.81×10^{-4}	$<1.64 \times 10^{-5}$	$<6.79 \times 10^{-6}$	4.41×10^{-5}	1.10×10^{-4}	1.54×10^{-4}
	(% of total)		<10.64	<4.40	28.64	71.36	100
	(% of feed)		<2.83	<1.17	7.59	18.40	25.99

(a) Total (g/sec) = kiln ash + cyclone ash + separator sludge + stack emissions

(b) % of total = individual residue stream flow (i.e. kiln ash)/Total

(c) % of feed = individual residue stream flow/waste stream flow

(d) % chromium = concentration of hexavalent chromium/total chromium conc. in residue stream

TABLE 45. HEAVY METAL FLOW RATES IN RESIDUE STREAMS
TEST TWO RESULTS

Metal		Waste Feed	Kiln Ash	Cyclone Ash	Separator Sludge	Stack Emissions	Total(a)
Arsenic	(g/sec)	3.68×10^{-3}	2.17×10^{-3}	1.46×10^{-3}	1.91×10^{-4}	4.40×10^{-6}	3.83×10^{-3}
	(% of total)(b)		56.68	38.21	5.00	0.12	100
	(% of feed)(c)		58.69	39.70	5.19	0.12	103.90
Cadmium	(g/sec)	1.80×10^{-4}	3.66×10^{-5}	2.46×10^{-7}	7.35×10^{-5}	2.90×10^{-5}	1.40×10^{-4}
	(% of total)		26.23	0.18	52.61	20.99	100
	(% of feed)		20.33	0.14	40.79	16.27	77.53
Hexavalent Chromium	(g/sec)			6.35×10^{-3}	1.67×10^{-4}	$<2.00 \times 10^{-5}$	6.52×10^{-3}
	(% of total)			97.39	2.61	<0.31	100
	(% chromium)(d)			19.22	0.50	<0.06	NA
Total Chromium	(g/sec)	1.38×10^{-1}	7.46×10^{-2}	3.72×10^{-2}	4.76×10^{-3}	1.10×10^{-4}	1.17×10^{-1}
	(% of total)		63.90	31.88	4.08	0.09	100
	(% of feed)		54.11	26.96	3.45	0.08	84.54
Toxics:							
Lead	(g/sec)	1.55×10^{-2}	2.92×10^{-3}	3.12×10^{-5}	3.27×10^{-3}	1.83×10^{-3}	8.05×10^{-3}
	(% of total)		36.28	0.39	40.60	22.73	100
	(% of feed)		18.82	0.20	21.06	11.79	51.88
Mercury	(g/sec)	6.15×10^{-4}	$<1.83 \times 10^{-5}$	$<7.52 \times 10^{-6}$	3.20×10^{-5}	1.50×10^{-4}	1.82×10^{-4}
	(% of total)		<10.05	<4.12	18.58	82.42	100
	(% of feed)		<2.98	<1.22	5.20	23.73	28.93

(a) Total (g/sec) = kiln ash + cyclone ash + seperator sludge + stack emissions

(b) % of total = individual residue stream flow (i.e. kiln ash)/Total x 100

(c) % of feed = individual residue stream flow/waste stream flow x 100

(d) % chromium = concentration of hexavalent chromium/total chromium conc. in residue stream x 100

Arsenic --

Only 0.12% to 0.17% of the arsenic was emitted from the stack. Over 90% of the arsenic remained in the hot end of the unit being equally distributed between the kiln ash and the cyclone ash. The results of recent studies at the EPA Combustion Research Facility in Jefferson, Arkansas, were in general agreement with this data with the following normalized partitioning for arsenic: kiln ash about 90%, scrubber water about 5%, and stack gas about 5% [25] Since arsenic forms many low boiling point compounds, this behavior is anomolous and it requires further study.

Cadmium and Lead --

The relative emission rates of cadmium and lead are very similar. Significant percentages of these metals were emitted from the stack gases. About 12% of the lead and 16% of the cadmium was emitted from the stack. This shows that air pollution equipment design is very important when feed materials contain large quantities of these metals. The greatest quantities of these metals exited the system with the separator sludge. Up to 19% of the lead and 20% of the cadmium were retained in the kiln ash. Less than 1% of the total lead and cadmium were retained in the cyclone ash.

Hexavalent Chromium --

Hexavalent chromium was found in maximum quantities in the cyclone ash but was not detected in the kiln ash. Since hexavalent chromium is soluble in aqueous media, this result shows that cyclone ash may have problems passing the criteria for EP-toxicity for chromium-containing wastes, but that kiln ash would not present a problem.

Small amounts of hexavalent chromium were present in the separator sludge. A possible explanation for this drop in hexavalent chromium from the cyclone ash to the separator sludge is that the process water dissolved the hexavalent chromium. However, analysis of chromium in the process water showed that chromium concentrations could only account for about 1% of the missing hexavalent chromium. The other possible explanation is that the hexavalent chromium reverted to the trivalent state in the SCC. Further investigation is warranted to determine the fate of hexavalent chromium.

Chromium --

Over 95% of the chromium was retained by the kiln and cyclone ash.

Mercury --

Although only 29% of the mercury in the original wastes was accounted for during the tests, from 70% to 82% of this mercury was emitted from the stack. High percentages of the mercury would be expected as stack emissions due to the high volatility of mercury and its compounds. The poor closure of the material balance may be caused by the small quantities of mercury present in the waste feed which tends to produce higher relative errors.

SECTION 8

MOBILE INCINERATOR OPERATING EXPERIENCE

After the system modifications were completed, the MIS operations were resumed on June 1, 1987. During the next two years, the MIS incinerated over 10,600,000 lb solids and 70,000 lb liquids, and many tests were conducted that advanced the understanding of the incineration process. These tests--consisting of the shakedown tests, trial burn tests, associated tests with vermiculate and brominated sludge feeds, and the metals emissions tests--were discussed in Sections 4, 5, 6, and 7. This section will cover the operating experiences in 1987, 1988, and 1989, and the knowledge gained from this experience. The specific areas covered are as follows:

- Processing summary covering the source, type of material, and amount of material incinerated.
- Brominated sludge delisting tests.
- Effect of feed characteristics on unit performance.
- Availability of the system and effect of the system modifications on availability.
- Maintenance activity required.

These topics, which include the lessons learned during this period, are discussed below.

PROCESSING SUMMARY

The incineration activities during 1987, 1988, and 1989 were characterized by constantly improving performance as deficiencies in the design and operation of the MIS were identified and corrected. Operations during each of these years are summarized below and in Table 46.

1987 Operations

Between June and September 1987, a total of 1,247,000 lb solids and 40,000 lb liquids was incinerated. This completed the incineration of materials from the first five sites--Denney Farm, Neosho Wastewater Technical School, Rusha Farm, Tally Farm, and Erwin Farm. Approximately 225,000 lb of trash from Region VII, 250,000 lb of trash from the above sites and from onsite, 160,000 lb solids and 8,000 lb liquids from the dioxin trial burn, and 49,000 lb brominated sludge were included in the above total. During this period, the effects of several feed characteristics were identified. This included the effect of organic chlorides, soil moisture,

TABLE 46. MIS OPERATIONS SUMMARY

Feed Source or Activity	Date of Activity	Total Hours	Pounds Processed		Avail.(a)	Avg. Rates (lb/hr)	
			Lb Solids	Lb Liquids	(%)	Tot. hr basis	Online hr basis
1985-1986							
Neosho and The Farms(b)	7/23/85-8/27/85	954	436,000	60,300	38.1	457	1201
Neosho and The Farms(b)	10/26/85-2/03/86	2853	1,495,000	107,300	54.0	524	971
1985-1986 Totals		3801	1,931,000	167,600	50.0	508	1015
1987							
Neosho and The Farms(c)	6/12-9/18	2212	1,095,000	31,300	54.8	495	900
RCRA/TSCA Trial Burn(d)	7/28-8/3 8/31-9/1	190	162,000	7,600	30.5	853	2793
1987 Totals		2399	1,257,000	38,900	53.1	524	986
1988-1989							
Baldwin Park(e)	2/22/88-4/27/88	1586	911,000	22,200	39.1	574	1469
Baldwin Park Trash(f)	8/02/88-8/12/88	253	136,000	3,800	58.9	538	913
Brominated Sludge Tests	4/28/88-5/01/88	78	49,000	0	55.1	628	1140
Verona	5/02/88-8/01/88	2215	3,097,000	3,000	59.8	1398	2338
Maintenance	8/12/88-8/31/88	0	0	0	0.0	0	0
Brominated Sludge	8/31/88-1/23/89	3392	2,161,000	1,400	60.8	637	1049
Closure(g)	1/24/89-4/15/89	1912	2,989,000	200	80.0	1563	1953
1988-1989 Totals		9436	9,343,000	30,600	60.7(h)	989	1629
1988-1989 Totals w/out sludge(i)		6044	7,182,000	29,200	60.6(h)	1188	1960
Totals for 1985-1989			12,531,000	237,100			
	GRAND TOTAL		12,768,000				

(a) % Availability =(Time Processing Solid Feed/Total Time) x 100.

(b) The Farms are Denney, Erwin, Rusha and Tally. Only small quantities of trash were processed.

(c) Included is approximately 475,000 lb of trash.

(d) The low availability was due to preparation time and a failed kiln bearing.

(e) The low availability was due to problems encountered during the start-up in February and March, 1988.

(f) Most of the material was trash consisting of wooden pallets and steel barrels with some soils.

(g) Due to Decontamination of the feed system the records stop on April 16. Incineration activities continued until April 22, 1989, chiefly on residues from cleaning the feed system.

(h) Availability calculation excludes the August, 1988 maintenance period.

(i) This data represents the operating summary for soils only in 1988-1989.

heating value, morphology, rheology, and ash fusion characteristics. Identification of these effects led to processing improvements consisting of the addition of a mist eliminator in the MX scrubber, redesign of the doctor blade in the main feed conveyor, addition of an auxiliary conveyor belt system, manual pre-preparation of hard-to-shred materials, and addition of a television camera at the outlet of the main feed conveyor. These improvements were instituted during a maintenance period occurring from September 1987 to February 1988 when the MIS was not operational.

1988 Operations

During 1988, most of the remaining dioxin contaminated materials from southwestern Missouri were incinerated; a scoping burn proved the feasibility of processing brominated sludge from the Syntex Springfield Site; the residues from incinerating brominated sludge were delisted as a hazardous waste; the fate of the heavy metals present in the brominated sludge was investigated; and the brominated sludge was incinerated.

A total of 5,983,000 lb solids and 28,900 lb liquids was incinerated from the three remaining dioxin Superfund sites in southwestern Missouri -- Baldwin Park, Syntex Verona, and Syntex Springfield. These materials consisted of contaminated soils and trash from Baldwin Park and Syntex Verona, and brominated sludge and trash from Syntex Springfield.

The conveyor belt system that was installed during March 1988 to feed material to the shredder approximately doubled the sustained processing capability of the MIS. The capacity increase is illustrated in Table 46 by comparing the production rates based on online hours for Closure, Verona, and Baldwin Park with those of Neosho and the Farms in previous years. The feed materials from these sources were composed mainly of soils having comparable characteristics. The lower production rates for brominated sludge and trash are caused by their high heating values and other characteristics that differ considerably from soil properties.

The conveyor belt system replaced the prior method of feeding, which involved filling steel drums with soil, transporting the drums between buildings with a forklift, raising the drums above the shredder, and manually dumping the contents into the shredder using a drum tipper. The new system allowed the placement of wastes directly on the conveyer using a front-end loader. The conveyer brought the material to the shredder. This system reduced the frequency of handling materials and decreased the labor requirements for feeding soil. This allowed the feeding crew to perform other productive tasks such as preparing feed materials that required pre-preparation for shredding, e.g., wooden pallets and metal drum rings. The crew could also more easily handle any problems that occurred without interrupting the feeding operation.

1989 Operations

During 1989, the main activities were incineration of the final 371,200 lb of brominated sludge and trash, and 1,400 lb of liquids from the Syntex Springfield site, and the incineration of the 2,989,000 lb of soil and trash associated with closure activities at the Denney Farm site. During the closure period, the MIS achieved its highest average hourly feed rate (1,563 lb/hr) and availability (80%).

BROMINATED SLUDGE DELISTING

The residues from incineration of the Syntex Springfield sludge were not covered by the 1985 delisting criteria. Delisting petitions are wastefeed specific, and the 1985 delisting petition only covered specific dioxin contaminated soils and solvents from Denney Farm and other nearby locations which were named in the delisting rule. Therefore, the byproducts from the incineration of Syntex Springfield sludge had to be delisted separately. A delisting petition was filed by Syntex, and delisting tests were conducted in September 1988. Ash and water samples were taken during four consecutive eight-hour test runs and analyzed for the delisting criteria established by OSW. MIS operating conditions for these test runs are presented in Table 39. Average feed rate was 1613 lb/hr for the four tests.

Tables 47 and 48 show that the residues met the criteria for all organic compounds, but the chromium content in the kiln and cyclone ash composite samples exceeded the criteria. As shown in Table 47, analyses for dioxins and furans were all nondetect and met the stringent criteria of 5 ppt in the ash and 2 ppq in the wastewater, expressed as 2,3,7,8-TCDD equivalents (Federal Register, Volume 53, No. 106, June 2, 1988). All other organic delisting compounds were also nondetect with the exception of 1,2-dichloromethane, which was detected at levels below the delisting criteria in both the process water and solid residue, as shown in Tables 47 and 48. Table 48 shows that the chromium contents in the EP toxicity leachate from the ash residue for two test runs (6.17 ppm in test 1, and 2.27 ppm in test 3) slightly exceeded the 1.6 ppm delisting criteria. Due to this result, the ash generated each day of operation when incinerating the sludge was sampled and analyzed for chromium in the EP toxicity leachate. The ash was sent to the landfill only after the analysis confirmed that chromium content met the delisting criteria.

TABLE 47. BROMINATED SLUDGE DELISTING RESULTS FOR PROCESS WATER

Compound	Delisting Criteria (ppt)	Quantitation Limits (ppt)	Test 1	Test 2	Test 3	Test 4
2378 & 2378 Substituted Cogeners:						
2,3,7,8-TCDD	See Table 29	0.120	ND (0.001)	ND (0.003)	ND (0.003)	ND (0.005)
2,3,7,8-TCDF		0.120	ND (0.002)	ND (0.003)	ND (0.003)	ND (0.005)
2,3,7,8-P5CDD		0.120	ND (0.003)	ND (0.003)	ND (0.003)	ND (0.008)
2,3,7,8-P5CDF		0.120	ND (0.003)	ND (0.003)	ND (0.003)	ND (0.008)
2,3,7,8-H6CDD		0.300	ND (0.003)	ND (0.003)	ND (0.003)	ND (0.008)
2,3,7,8-H6CDF		0.300	ND (0.003)	ND (0.003)	ND (0.003)	ND (0.013)
Total-TCDD		0.120	ND (0.020)	ND (0.008)	ND (0.010)	ND (0.005)
Total-TCDF		0.120	ND (0.018)	ND (0.018)	ND (0.016)	ND (0.005)
Total-P5CDD		0.120	ND (0.007)	ND (0.002)	ND (0.009)	ND (0.008)
Total-P5CDF		0.120	ND (0.015)	ND (0.014)	ND (0.012)	ND (0.008)
Total-H6CDD		0.300	ND (0.023)	ND (0.014)	ND (0.029)	ND (0.008)
Total-H6CDF		0.300	ND (0.012)	ND (0.007)	ND (0.007)	ND (0.008)
Metals:						
Arsenic	610,000		ND (50,000)	ND (50,000)	ND (50,000)	ND (50,000)
Barium	12,000,000		ND (200,000)	ND (207,000)	ND (200,000)	ND (200,000)
Cadmium	120,000		ND (5,000)	ND (5,000)	ND (5,000)	ND (5,000)
Chromium	610,000		50,000	12,000	17,000	10,000
Lead	610,000		ND (36,000)	ND (36,000)	ND (36,000)	ND (36,000)
Mercury	20,000		ND (2000)	ND (2000)	ND (2000)	ND (2000)
Nickel	6,100,000		ND (40,000)	ND (40,000)	ND (40,000)	ND (40,000)
Selenium	120,000		ND (31,000)	ND (31,000)	ND (31,000)	ND (31,000)
Silver	610,000		ND (10,000)	ND (10,000)	ND (10,000)	ND (10,000)
Cyanide	2,400,000		ND (25,000)	ND (25,000)	ND (25,000)	ND (25,000)

(continued)

TABLE 47 (Continued)

Compound	Delisting Criteria (ppt)	Quantitation Limits (ppt)	Test 1	Test 2	Test 3	Test 4
Semivolatiles:						
Benzo(a)anthracene	100	10,000(a)	ND (10,000)	ND (10,000)	ND (10,000)	ND (10,000)
Benzo(a)pyrene	40	10,000(a)	ND (10,000)	ND (10,000)	ND (10,000)	ND (10,000)
Benzo(b)fluoranthene	200	10,000(a)	ND (10,000)	ND (10,000)	ND (10,000)	ND (10,000)
Chrysene	2000	10,000(a)	ND (10,000)	ND (10,000)	ND (10,000)	ND (10,000)
Dibenz(a,h)anthracene	9	10,000(a)	ND (10,000)	ND (10,000)	ND (10,000)	ND (10,000)
Indeno(123-cd)pyrene	2000	10,000(a)	ND (10,000)	ND (10,000)	ND (10,000)	ND (10,000)
PCBs	100	500(a)	ND (500)	ND (500)	ND (500)	ND (500)
1,2,4,5-Tetrachlorobenzene	130,000	10,000	ND (10,000)	ND (10,000)	ND (10,000)	ND (10,000)
2,3,4,6-Tetrachlorophenol	12,000,000	10,000	ND (10,000)	ND (10,000)	ND (10,000)	ND (10,000)
2,4,5-Trichlorophenol	49,000,000	5,000	ND (5,000)	ND (5,000)	ND (5,000)	ND (5,000)
2,4,6-Trichlorophenol	20,000	10,000	ND (10,000)	ND (10,000)	ND (10,000)	ND (10,000)
Volatiles:						
Chloroform	70,000	5,000	ND (5,000)	ND (5,000)	ND (5,000)	ND (5,000)
1,2-Dichloroethane	60,000	5,000	ND (5,000)	ND (5,000)	ND (5,000)	ND (5,00)
Dichloromethane	60,000		10,000	13,000	39,000	12,000
Toluene	120,000,000	5,000	ND (5,000)	ND (5,000)	ND (5,000)	ND (5,000)
Trichloroethylene	40,000	5,000	ND (5,000)	ND (5,000)	ND (5,000)	ND (5,000)

ND = not detected

(a) Compounds with delisting levels below the Minimum Detection Limit must be not detected.

TABLE 48. BROMINATED SLUDGE DELISTING RESULTS FOR KILN AND CYCLONE ASH COMPOSITE

Compound	Delisting Criteria (ppt)	Quantitation Limits (ppt)	Test 1	Test 2	Test 3	Test 4
2378 & 2378 Substituted Cogeners:						
2,3,7,8-TCDD	See Table 29	15	ND (0.305)	ND (0.585)	ND (0.603)	ND (1.07)
2,3,7,8-TCDF		15	ND (0.439)	ND (0.705)	ND (0.655)	ND (0.955)
2,3,7,8-P5CDD		15	ND (0.613)	ND (1.08)	ND (0.853)	ND (1.53)
2,3,7,8-P5CDF		15	ND (0.362)	ND (0.810)	ND (0.775)	ND (1.24)
2,3,7,8-H6CDD		37	ND (0.995)	ND (1.69)	ND (1.52)	ND (3.31)
2,3,7,8-H6CDF		37	ND (2.31)	ND (1.61)	ND (1.49)	ND (2.63)
Total-TCDD		15	ND (0.305)	ND (0.585)	ND (0.603)	ND (1.07)
Total-TCDF		15	ND (0.439)	ND (0.705)	ND (0.655)	ND (0.955)
Total-P5CDD		15	ND (2.34)	ND (1.08)	ND (0.853)	ND (1.53)
Total-P5CDF		15	ND (0.350)	ND (9.65)	ND (2.73)	ND (1.19)
Total-H6CDD		37	ND (0.853)	ND (1.53)	ND (1.37)	ND (2.99)
Total-H6CDF		37	ND (1.66)	ND (1.15)	ND (1.06)	ND (1.87)
Metals:						
Arsenic	1,600,000		ND (50,000)	ND (50,000)	ND (86,000)	ND (50,000)
Barium	32,000,000		567,000	756,000	738,000	779,000
Cadmium	320,000		ND (5,000)	ND (5,000)	ND (5,000)	ND (5,000)
Chromium	1,600,000		6,190,000	157,000	2,270,000	10,000
Lead	1,600,000		ND (36,000)	ND (36,000)	ND (36,000)	ND (36,000)
Mercury	65,000		ND (2000)	ND (2000)	ND (2000)	ND (2000)
Nickel	16,000,000		ND (40,000)	ND (40,000)	ND (40,000)	ND (40,000)
Selenium	320,000		ND (50,000)	ND (31,000)	ND (31,000)	ND (31,000)
Silver	1,600,000		ND (10,000)	ND (10,000)	ND (10,000)	ND (10,000)
Cyanide	6,500,000		ND (25,000)	ND (25,000)	ND (25,000)	ND (25,000)

(continued)

TABLE 48 (Continued)

Compound	Delisting Criteria (ppt)	Quantitation Limits (ppt)	Test 1	Test 2	Test 3	Test 4
Semivolatiles:						
Benzo(a)anthracene	1,100,000	330,000	ND (330,000)	ND (330,000)	ND (330,000)	ND (330,000)
Benzo(a)pyrene	430,000	330,000	ND (330,000)	ND (330,000)	ND (330,000)	ND (330,000)
Benzo(b)fluoranthene	1,800,000	330,000	ND (330,000)	ND (330,000)	ND (330,000)	ND (330,000)
Chrysene	170,000,000	330,000	ND (330,000)	ND (330,000)	ND (330,000)	ND (330,000)
Dibenz(a,h)anthracene	83,000	330,000(a)	ND (330,000)	ND (330,000)	ND (330,000)	ND (330,000)
Indeno(123-cd)pyrene	330,000,000	330,000	ND (330,000)	ND (330,000)	ND (330,000)	ND (330,000)
PCBs	310,000	880,000(a)	ND (400,000)	ND (80,000)	ND (80,000)	ND (880,000)
1,2,4,5-Tetrachlorobenzene	720,000,000	330,000	ND (330,000)	ND (330,000)	ND (330,000)	ND (330,000)
2,4,6-Trichlorophenol	3,900,000	330,000	ND (330,000)	ND (330,000)	ND (330,000)	ND (330,000)
Volatiles:						
Chloroform	5,400,000	5,000	ND (5,000)	ND (5,000)	ND (5,000)	ND (5,000)
1,2-Dichloroethane	4,100,000	5,000	ND (5,000)	ND (5,000)	ND (5,000)	ND (5,00)
Dichloromethane	2,400,000		52,000	14,000	6,000	12,000
Trichloroethylene	6,600,000	5,000	ND (5,000)	ND (5,000)	ND (5,000)	ND (5,000)

ND = not detected

(a) Compounds with delisting levels below the Minimum Detection Limit must be not detected.

Chromium In Solid Residue

Two interesting findings were associated with the failure of the ash to pass delisting criteria in tests 1 and 3. The testing on the fate of heavy metals, which involved separate sampling of the kiln and cyclone ash, showed that the cyclone ash contained detectable levels of hexavalent chromium, but the kiln ash did not have detectable levels. The EP toxicity analysis showed that the problem of excessive chromium was associated with the cyclone ash. Furthermore, the barrels of cyclone ash were sampled again after waiting several days. The results from this sampling showed that the chromium content of the EP toxicity leachate had decreased (Table 49). These results should be investigated further since they indicate that hexavalent chromium may be stabilized as another form of chromium due to its high reactivity.

EFFECT OF FEED CHARACTERISTICS ON MIS PERFORMANCE

The various feed materials processed in the MIS have exhibited large differences in characteristics which have affected the performance of the MIS [26]. The operating experiences with the MIS have increased the understanding of the interplay of feed characteristics with the hardware, as follows:

- The effect of feed characteristics on feed rates and availability.
- The parts of the system affected by particular feed characteristics and the operating limits imposed by the characteristics on capacity and reliability.
- Actions required to mitigate problems caused by the interaction of feed characteristics with the MIS.

These factors are discussed below.

Feed Characteristics

Both the physical and chemical properties of the feed determine incineration system performance [27]. Important physical properties include: heating value, morphology, density, rheology, ash particle-size distribution, and fusion characteristics. Important chemical properties include the composition of the feed as shown by: organic content, organic hazardous constituents, acid-forming elements such as sulfur and the halogens, moisture content, and inorganic ash components. These properties can affect the operating parameters, the capacity, and the reliability of the incineration system. Many of these properties are interdependent as far as their effect on the incinerator performance. The manner in which these properties affected the performance of the MIS is summarized in Table 50. The information is applicable to other incineration systems.

TABLE 49. CHROMIUM IN EP TOXICITY LEACHATE FOR ASH SAMPLES

Type of Sample	Date of Sample	Ash Drum(s)	Delisting Limit (ppm)	Chromium Content (ppm)
Case 1.				
Kiln+Cyclone Ash	October 11,1988	7601-7637	1.6	4.90
Kiln+Cyclone Ash	November 4,1988	7601-7637	1.6	0.09
Case 2.				
Kiln+Cyclone Ash	November 3,1988	7956-7972	1.6	4.50
Kiln+Cyclone Ash	November 3,1988	8029-8032	1.6	1.92
Kiln+Cyclone Ash	November 9,1988	7956-7972	1.6	0.56
Kiln+Cyclone Ash	November 9,1988	8029-8032	1.6	ND
(samples of November 9 were combined)				

All samples are composite samples.

TABLE 50. PROPERTIES AFFECTING INCINERATION SYSTEM PERFORMANCE

Property	Hardware affected	Operating parameter affected	Effect on performance	Feeds of concern
Heating value	Rotary kiln	Rotary kiln temperature, Flue gas residence time in SCC	Feed capacity, Fuel usage	Plastics, Trash, Wooden pallets, Brominated sludge
Morphology	Feed system, Ash gates	Feed preparation	Feed interruptions	Steel barrels, Steel rings, Plastics, Wooden pallets
Density	Rotary kiln, Corbel	Weight of material held by kiln	Feed capacity	Vermiculite
Rheology	Feed system, Rotary kiln	Frequency of feeding, Ash purity, Kiln rotation speed	Feed capacity	Brominated sludge
Halogen and sulfur content	Quench system, Air pollution control equipment design and operation	Pump cavitation, pH control, Blowdown rate, Particulate emissions	Feed capacity, Caustic usage	Trial burn mixture, Brominated sludge
Moisture	Feed system, SCC	Flue gas residence time in SCC, Rotary kiln temperature	Feed capacity, Fuel usage	Muddy soil, Brominated sludge
Particle size distribution	Cyclone, SCC, Ducts, Wet Electrostatic Precipitator (WEP), Instrumentation	Kiln draft, Particulate emissions Excess oxygen control, Temperature Control	Fouling of ducts, cyclone, SCC, process water system, & Instruments	Erwin Farm soil, Brominated sludge, Vermiculite
Ash fusion characteristics (Determined by chemical characteristics, e.g. alkalis)	Rotary kiln, Cyclone, Ducts, Quench elbow, Instrumentation	Kiln draft, Temperature, Excess O_2 control	Slagging of kiln, Plugging of instruments & downstream equipment	Plastics, Trash, Brominated sludge

Effect of Heating Value

Heating value of the feed material affects both feed capacity and fuel usage of the incinerator. As the heating value of feed material increases, kiln temperature can increase and sometimes become uncontrollable. The kiln also requires greater amounts of oxidant to complete combustion and greater quantities of inert material to control kiln temperature. This temperature increase can limit feed capacity. The MIS reached its capacity limit at 4.5 to 5.5 million btu/hr heat input to the kiln. Feed materials, such as plastics, trash, wooden pallets, and brominated sludge, had capacity constraints caused by high calorific values. Maximum feed capacities for these materials ranged from 200 lb/hr for pure plastics to 1900 lb/hr for brominated sludge as shown in Table 51.

Solid materials with high calorific values cause transient behaviors that sometimes further limit feed capacity. Plastics, trash, and wood ignite almost immediately after they are fed to the kiln. Gases evolved from these materials burn rapidly producing a sharp increase in kiln temperature and a sharp decrease in excess oxygen. Prior to the 1987 modifications, the MIS was extremely sensitive to these transients, which caused many feed stoppages.

After the addition of the LINDE^R Oxygen Combustion System (OCS), the MIS response to the above transient behavior was improved, and feed stoppages due to low oxygen were virtually eliminated [28]. However, there were still many feed cut-offs caused by excessive kiln temperatures. These were minimized by operating the kiln at the lower end (1450°F) of the temperature range allowed by the RCRA permit, and by using water injection to control kiln temperatures.

For brominated sludge, the behavior of the MIS was somewhat different. Large oscillations of the kiln temperature and excess oxygen level occurred even when the kiln was operated at 1450°F. The resulting over-temperatures (greater than 1900°F) caused feed cut-offs and shutdowns of the kiln burners. Loss of the burners increased the length of the feed cut-off period. The operating changes required to alleviate this phenomenon are described below.

To reduce the amplitude of the temperature excursions, an automatic feed cut-off was introduced into the kiln control system. This stopped feed whenever the kiln temperature exceeded 1730°F or the oxygen level dropped below 4% (wet). This action minimized over-temperature incidents, but the oscillation frequency was still large. As shown in Figure 23, about four oscillations occurred per hour. Feed was cut off for approximately eight minutes during each oscillation. Feed rate was limited to 1000 lb/hr under these operating conditions.

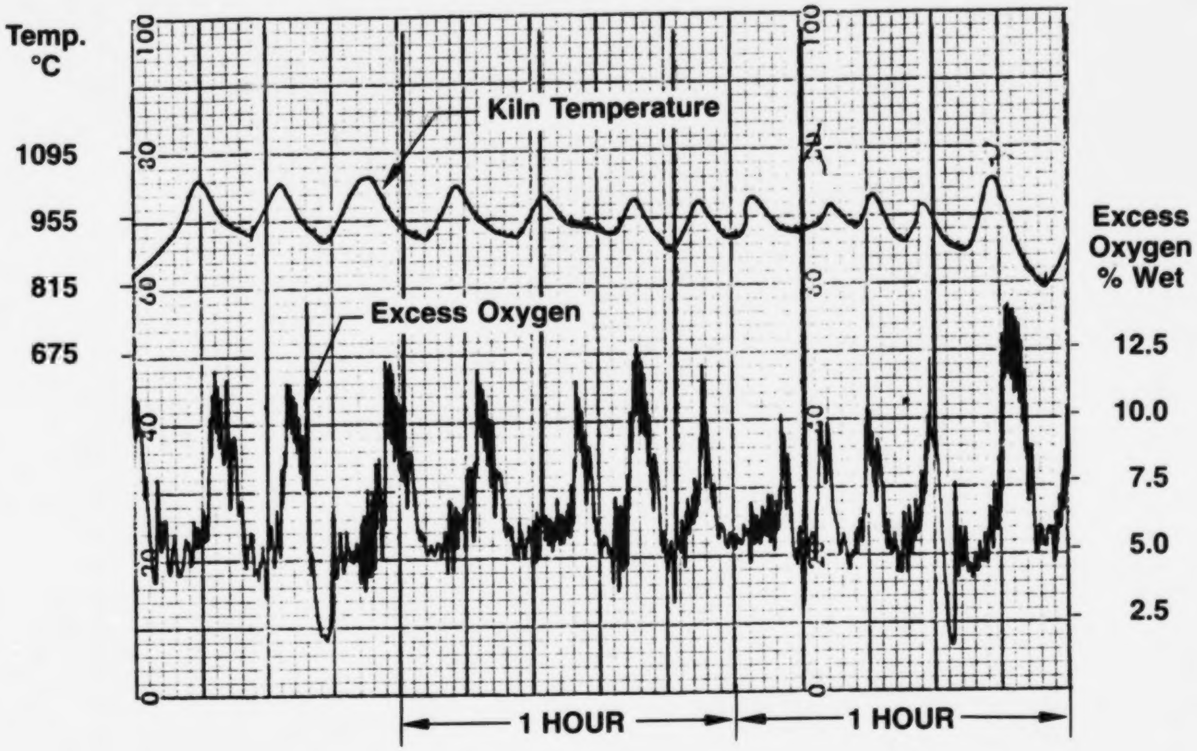
TABLE 51. FEED CHARACTERISTICS AND EFFECT OF VARIOUS FEEDS ON MIS PERFORMANCE

Feed material	% of Particles <100 microns (Ash)	Heating value (BTU/lb)	% Moisture	Organic content (%)	Halogen content (%)	Kiln temp. (°F)	Maximum feed rate (lb/hr)	Limitation on feed	Operating concerns
Denney Farm soil-clay (1985-1986 before mods) Desnity = 77 lb/ft^3	4.8	85	20	2.5	0.13	1,600-1,700	2,000	SCC res. time, Ram capacity	Jamming of ram, 3-day SCC cleanout req. every 20 days
(1987-1988 after mods)	"	"	"	"	"	1,450-1,500	5,000 dry	Overflow of kiln corbel	
Mud + Soil	"	"	>70	"	"	"	2,500 mud	Doctor blade jamming	
Mud + Plastics	"	2,700	"	"	"	"	1,500	Doctor blade, Kiln Slagging, Kiln temp. BTU input	3-day kiln cleanout Cleanout every 10 days
Erwin Farm soil-silt (1985-1986 before mods)	33.4		20			1,600-1,700	2,000	SCC res. time, Ram capacity	Jamming of ram, 3-day SCC cleanout every 5 days
(1987-1988 after mods)	"	"	"	"	"	1,450-1,500	5,000 dry	Overflow of kiln corbel	
Mud + Soil	"	"	>70	"	"	"	2,500 mud	Doctor blade jamming	
Mud + Plastics	"	2,700	"	"	"	"	1,500	Doctor blade, Kiln Slagging, Kiln temp. BTU input	3-day kiln cleanout every 10 days
Plastics & trash Density = 56-137 lb/ft^3	0	6,500-18,900	0-10	50-100	0-57	1,450-1,500	200-700	Doctor blade jamming, kiln slagging, Kiln temp., BTU input	3-day kiln cleanout every 10 days

(continued)

TABLE 51 (continued)

Feed material	% of Particles <100 microns (Ash)	Heating value (BTU/lb)	% Moisture	Organic content (%)	Halogen content (%)	Kiln temp. (°F)	Maximum feed rate (lb/hr)	Limitation on feed	Operating concerns
Wooden pallets Density = 31-50 lb/ft^3	0	6,300	20	80	0	1,650-1,700	715	Kiln temp., BTU input	Cut into small pieces
Steel barrels	0	0	0	0	0	1,450-1,500	190-275	Shredder capability	Dull teeth causes balling and ash gate jamming
Vermiculite	0	0	--	0	0	1,450-1,500	800	Ram capacity	
Brominated sludge	86	2,650-6,200	35-42	15-34	1	1,650-1,900	815-2,000	Kiln temp., Solids residence time, BTU input.	3-day system clean-out every 12 days, Fouling of duct-work between kiln and SCC, Fouling of instrumentation, Draft control
Trial burn mixture									
Solids	--	340	19.8	4-5	2.6	1475-1670	3700-4050	Quench system pump Cavitation at 114 kg/hr organic chloride input	Quench system instability, Process water TDS
Liquids	NA	7150-7525	0	100	19.6	" "	145-350		



NOTES:
- **Brominated Sludge**
- **September 2, 1988**
- **Before Operating Changes**

Figure 23. Oscillations in temperature and excess oxygen in rotary kiln.

Observations of the kiln during the oscillations showed that the sludge was not igniting rapidly. Several batches of sludge would be fed by the ram before ignition occurred. After ignition, flame would fill the kiln, and oxygen flow and temperature would increase rapidly. After the sludge had burned several minutes, the flames would extinguish, and the oxygen flow and temperature would decrease rapidly to complete the cycle of oscillation. It became apparent that steady ignition of the material was required to prevent the oscillations.

The kiln temperature was increased from 1450°F to 1650°F to provide the necessary energy to evaporate the water and volatile organics so that ignition could be sustained. This operating change was successful in reducing the oscillations to a minimum as shown in Figure 24. Maximum feed rate was increased to 2000 lb/hr by the above changes.

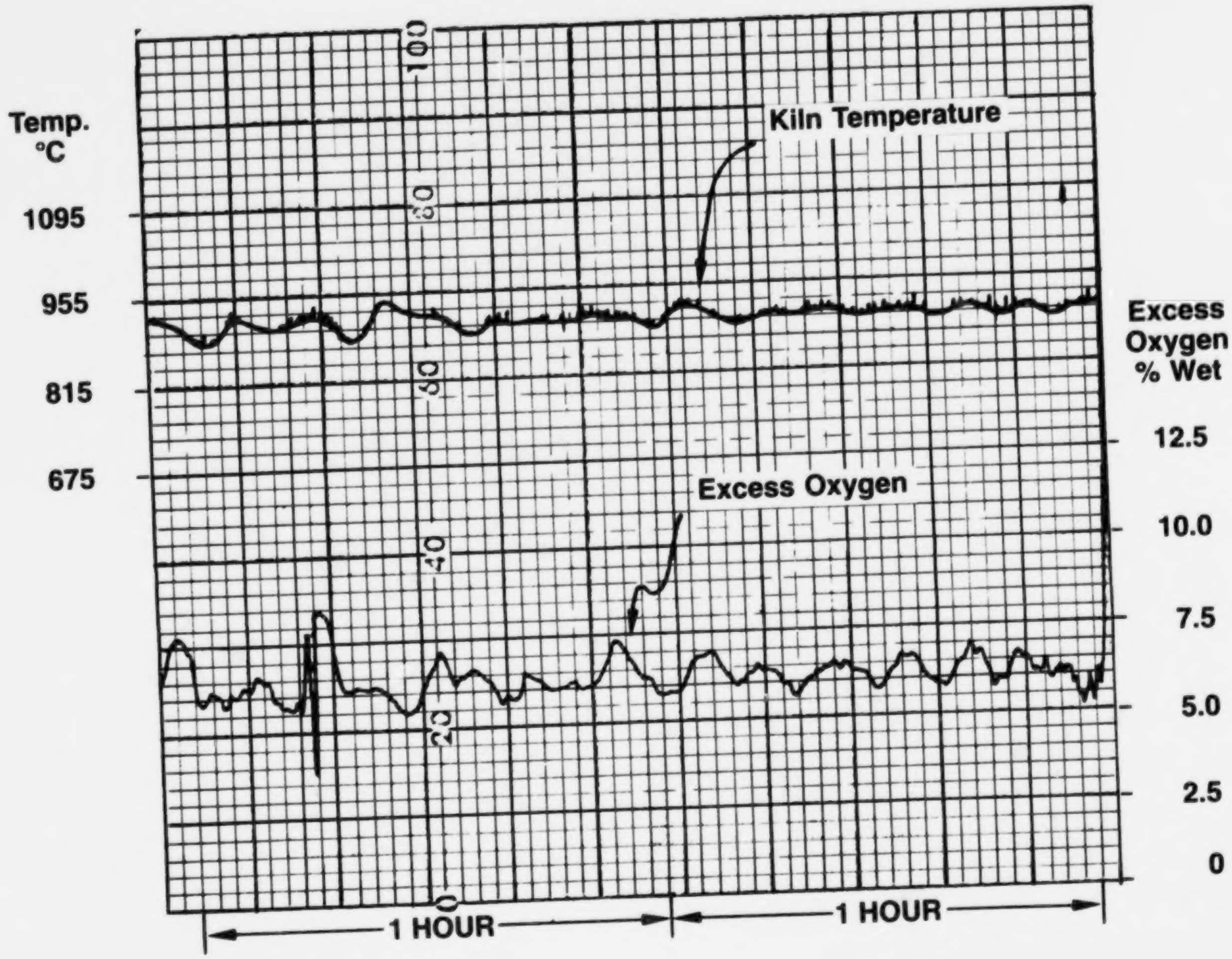
For feeds with high heat content such as brominated sludge, the capacity of the MIS is increased by water injection. Due to its high heat capacity, water provides a very effective heat sink. Consequently, when it is used to control kiln temperature, moisture increases the SCC residence time as compared to the use of excess air. Figure 25 shows that the use of water injection can increase capacity by about 20% over the use of excess air at a given SCC residence time. The use of oxygen in the kiln enhances the effect of water injection by allowing further capacity increases. At an enrichment to 40% O_2 in the combustion air, capacity can increase by 60%.

Effect of Morphology

The morphology of the feed material affects the feed system by causing periodic jams. Most of these problems are caused by materials that are poorly prepared by the shredder due to their morphological characteristics. Problem materials consist of wooden pallets, metal drum closure rings, plastics, trash, clothing, and mud.

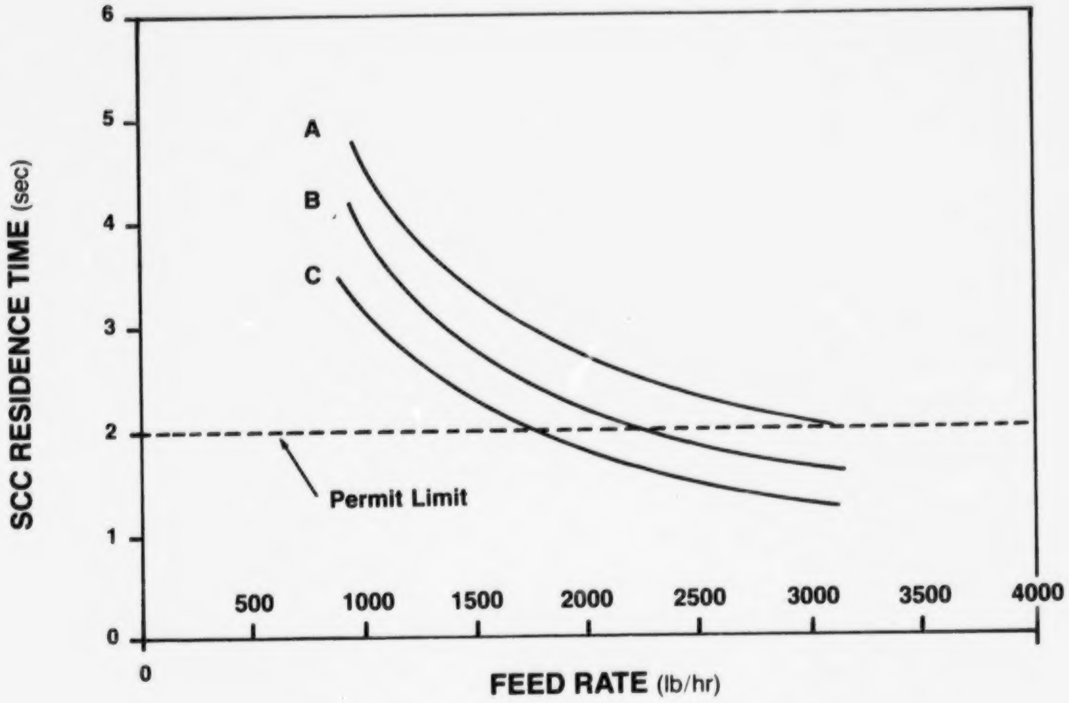
The feeding of these materials restricts the MIS capacity. As shown in Table 51, relatively dry soils can be fed at rates up to 5000 lb/hr but the presence of plastics and mud reduces the feed rate to 1500 lb/hr.

The shredder is used to prepare the solid feed materials for incineration. For most materials, the shredder works extremely well. However, wooden pallets and metal drum closure rings often cause feed blockages when shredded in the present equipment. While the shredder breaks most of the wooden pallet into 2-in. wood chips, an occasional board will position itself to go through the shredder as a 2-in.-wide by 4-ft-long sliver. The same is true for the drum lid rings. The shredder sometimes drags a ring through, straightening it



NOTES:
- Brominated Sludge
- September 8, 1988
- After Operating Changes

Figure 24. Kiln temperature and excess oxygen after operating change.



NOTES:

Solid Feed Heating Value	**2700 BTU/lb**
Kiln Temperature	**1697°F**
SCC Temperature	**2192°F**

A – Water injection using 40% oxygen-enriched air for combustion

B – Water injection using air for combustion

C – Air cooled using either air or 40% oxygen-enriched air for combustion

Figure 25. Effect of cooling media on SCC residence time.

but not cutting it. In each case, plugging of the conveyor, weigh scale, or ram follows. The best solution has been to manually separate and prepare these feed materials by cutting them into small pieces (about 10-in. in length) prior to shredding.

The shredder is unable to handle pipe or thick metal pieces. These must be manually classified, cut to proper size, and placed on the main feed conveyor downstream of the shredder.

The shredder also performs poorly on materials such as plastic, clothing, trash, and mud. These poorly shredded materials often jam at the doctor blade or restricting dam that was originally used to level the granular material on the conveyor belt as the belt exits the shredder hopper. The doctor blade works quite well for granular material but it creats large blockages when materials such as shredded plastic, clothing, trash, metal, or mud are fed. A roller has been installed to replace the doctor blade, and this has reduced the number of jamming incidents.

In one instance, the combination of metal and mud damaged the main conveyor belt. The belt was slit for 69 ft of its 85-ft length by a metal shard embedded in mud. The clump of mud containing the shard had stuck to the belt, passed under the top-end belt wiper, and lodged in the underside rollers. The top-end wiper was repositioned to provide a more positive wiping action.

Finely granulated material affected the operation of the ram feeder. It would bypass the ram head and collect on the backside. The material on the backside would periodically prevent the ram from fully retracting. A small chain-plug conveyor was installed and timed to convey the bypassed material to the front side of the ram. This solution has worked quite well.

Effect of Density

The density of the feed determines capacity for many feed materials. For feeds of typical densities (80 lb/ft^3), such as soils, the maximum feed rates were 5000 lb/hr. The maximum feed rate was obtained at a kiln revolution rate of 1.6 rpm, which gives a typical solids residence time of 30 minutes. For low density materials such as vermiculite (6 lb/ft^3), feed rates up to 800 lb/hr were feasible.

The density of the feed determines capacity for many feed materials, because the density of a material is inversely proportional to the volume it occupies, and the ultimate feed rate for a given material is limited by the volume capacity of the kiln. The volume capacity of the kiln is determined by the amount of material that can be held by the kiln without overflowing the corbel. The corbel is an annular lip on the front end of the kiln, which rotates with the kiln. There is a space between the corbel and the front plate of the kiln. When material gets into this space, the seals of the kiln are damaged. The maximum volume that the kiln can hold without spilling over the corbel is about 15% of its total volume.

Effect of Rheology

The rheology of the material affects either the feed system or the decontamination behavior. Muddy soils fed to the MIS formed clumps of material, which were caught by the doctor blade and also would stick to the conveyor belt, weigh scale and ram trough. The resulting buildup would periodically plug various parts of the feed system thus reducing overall feed rates to about 2,500 lb/hr. This is approximately 50% of the maximum rates achievable with dry soils. Addition of vermiculite has eliminated the sticking of the muddy material while adding only a small amount to the throughput weight.

The brominated sludge that was fed had a tendency to form balls up to 3-in. in diameter. Since the time required for burnout of a sphere is proportional to the square of its diameter, the large balls require a much longer residence time in the kiln for decontamination. At the normal 1.6 rpm speed of the kiln for soil, small smoking particles would exit the kiln with the kiln ash. This required limiting feed rate to about 1,000 lb/hr. However, when the residence time of the sludge was increased by reducing the revolution speed to 0.8 rpm, feed rates up to 2,000 lb/hr were achievable without smoking.

Effect of Halogen and Sulfur Content

Incineration of brominated and chlorinated wastes generate the acid gases hydrogen bromide (HBr) and hydrogen chloride (HCl). These acid gases affect the capacity, the blowdown rates that control total dissolved solids (TDS) in the process water system, and the particulate emissions.

A capacity limit of 250 lb/hr of acid-forming organic chlorides was encountered during the 1987 trial burn [5]. The capacity limit was caused by pump cavitation in the quench system, which cools the gases exiting from the SCC to about 190°F. The cavitation reduced the quench water flow rate, which activates the protective instrumentation resulting in cut-off of the feed and shutdown of the burners. This cavitation was produced by excessive chlorinated waste feed rate as follows: The quench water is treated with caustic solution to neutralize acid gases. Reaction between HCl in the combustion gases and sodium hydroxide (NaOH) in the quench sump produces effervescence. The amount of effervescence increases to violent levels as HCl flow rate increases. The violent effervescence reduces the available net positive suction head (NPSH) of the pump, which causes cavitation at very high HCl loads.

High organic chloride loads also affect particulate emissions through the phenomenon of mist carry-over into the stack. The amount of carry-over is determined by both the HCl loading of the flue gas and the TDS of the process water [24].

In tests performed prior to the trial burn, particulate emissions were found to exceed the allowable emissions (0.08 gr/dscf) by as much as a factor of three. The relationship between particulate emissions and organic chloride loading is shown in Figure 11. Table 10 presents the analysis of the Method 5 particulate filter cakes, which shows that the major portion of the particulate was sodium chloride (NaCl) and sodium hydroxide (NaOH). The emissions were brought into compliance after a mist eliminator was installed.

However, data taken during the 1987 trial burn showed that TDS of the process water also affected particulate emissions. As shown in Figure 13, particulate emissions were proportional to TDS during the trial burn tests. The data shows that operation with TDS at 20,000 ppm adequately controls particulate levels at high chlorine loadings.

The TDS is controlled by adjusting the blowdown rates as follows: For a chlorinated waste 3.63 lb NaCl is formed per lb Cl in the waste. To maintain the TDS at 20,000 ppm, 181 lb of process water must be drawn from the system for every pound of Cl processed. This illustrates that the acid content determines the required process water blowdown rate.

Effect of Moisture

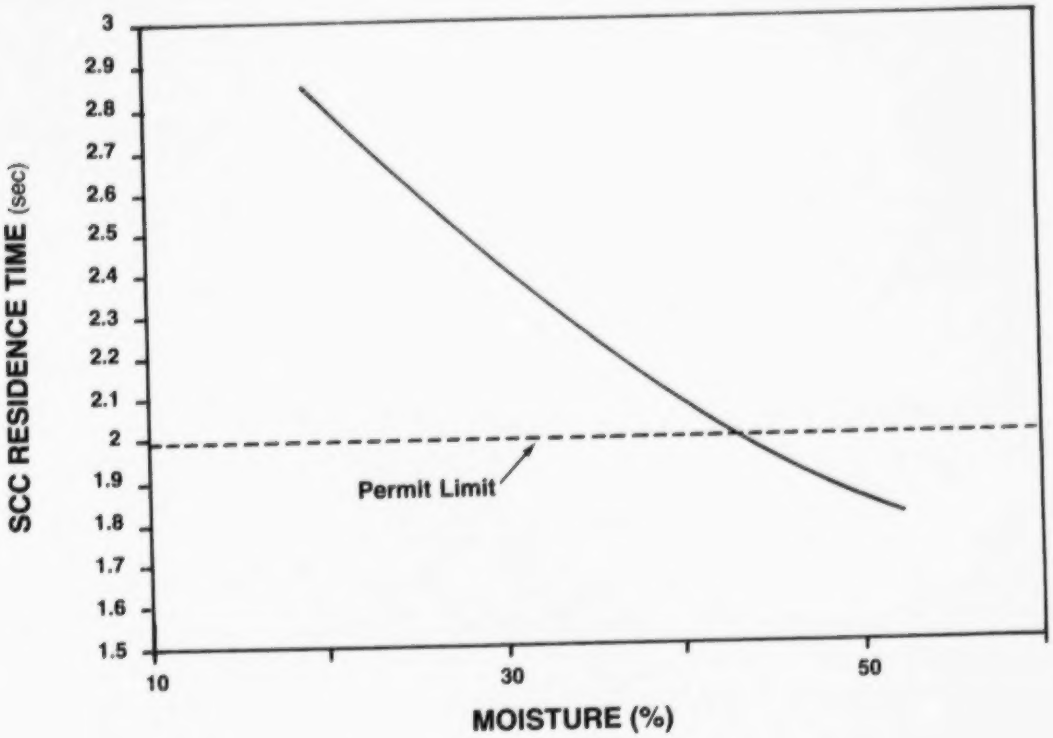
Moisture content affects incinerator performance and can adversely affect rheological behavior as described above. Depending upon the heat content of the waste, moisture can either improve or impede incinerator performance.

When using feeds with high heat content moisture acts as a heat sink to control kiln temperatures.

Conversely, when using feeds with low heat content, moisture increases auxiliary fuel requirements and decreases SCC residence time causing a capacity debit. The effect of moisture on SCC residence time is shown in Figure 26.

Effect of Particle Size Distribution

The particle size distribution of the ash generated from the waste determines the amount of particulate carry-over from the rotary kiln to the rest of the system. The importance of



NOTES:

Solid Feed Rate	4004 lb/hr
Kiln Temperature	1697°F
SCC Temperature	2192°F
30% Oxygen-Enriched Air	

Figure 26. Effect of feed moisture content on SCC residence time.

this characteristic can be demonstrated by the MIS experience with Denney Farm soil and Erwin Farm soil. As shown in Table 1, Denney Farm soil is much coarser than the Erwin Farm soil. Up to 25% of the Erwin Farm soil would carry over from the kiln to the SCC. This caused a rapid buildup of solids in the SCC. The solids buildup necessitated a 70-hr shutdown for removal of the slag after each 96 to 120 hr of operation (99,000 lb of soil processed). The behavior of the silt caused the unit to be unavailable for operation an average of 40% of the time due to the need to clean out the SCC. On the other hand, the unit could process the coarser Denney Farm soil for about 600 hours (595,000 lb of soil processed) before a shutdown for slag removal from the SCC was required. The unit was unavailable for 10% of the time due to SCC clean-outs with the coarser Denney Farm soil. In both cases, the buildup of solids in the SCC significantly reduced the availability of the incinerator.

The problem was mitigated in 1987 when a cyclone was added, between the kiln and the SCC, to remove the fines carried over from the kiln. The system operated over a three-month period and processed over 1,000,000 lb of solid material without requiring a shutdown for slag removal from the SCC.

Although the cyclone has alleviated the solids buildup in the SCC, fine particulates still have caused problems with the operating instruments. The large number of fine particulates associated with brominated sludge fouled the kiln oxygen meter and the SCC thermocouple about once every eight hours. This increased the number of over-temperature incidents in the rotary kiln, caused the incinerator feed cutoff to actuate due to a false SCC low temperature measurement, and increased the fuel flow to SCC burners. The thermocouple problems have been eased by changing the thermocouple location and using a thermowell rather than an aspirating thermocouple. No satisfactory solution has been found for the kiln oxygen measurement.

Effect of Ash Fusion Characteristics

The ash fusion characteristics of some feed materials caused the formation of hard slag deposits in the kiln; consolidated deposits in the ductwork between the kiln and cyclone, between the cyclone and SCC, and in the cyclone exit tube; and consolidated deposits in the SCC exit venturi. The ash fusion characteristics are determined by the chemical composition of the ash.

Ashes containing elements such as sodium (Na) and potassium (K) have low slagging temperatures. Ashes from plastics, glasses, wood, and other components of trash are rich in these compounds. The increased slagging tendency of trash was experienced in the rotary kiln, which required a system shutdown about every ten days to remove the slag buildup caused by incineration of trash.

Ashes containing significant quantities of calcium (Ca), iron (Fe), sulfur (S), or phosphorous (P) have moderate slagging temperatures. Although brominated sludge, containing both Ca and S, did not slag the kiln, the ash produced a consolidated deposit, shown in Figure 27, which fouled the ductwork between the kiln and the SCC. A consolidated deposit also occasionally formed in the quench elbow upstream of the quench nozzles. This fouling necessitated a system shutdown about every twelve days to remove the deposits.

Samples of the deposits were analyzed to determine the mechanism of deposition. More details on this topic are provided in reference [29]. The deposit mechanism was found to be similar to those operative in boilers fired with subbituminous coal. The deposits were formed by sintering of calcium sulfate ($CaSO_4$) in the temperature range of 1600°F and 1800°F in an ash containing 14% $CaSO_4$, 23% calcium oxide (CaO), and about 2.5% sodium oxide (Na_2O). The formation of fused calcium silicates as a result of the decomposition of $CaSO_4$ in the presence of quartz and aluminosilicates between 1600°F - 1800°F was also an important factor in the mechanism of deposition. A photomicrograph showing the sintering is presented in Figure 28. Table 52 gives the bulk composition of the deposit from the cyclone riser.

Most ashes consist mainly of aluminum (Al) and silicon (Si), which generally have good fusion characteristics (fusion temperatures above 3000°F). Both the Denney Farm and Erwin soils were composed mainly of SiO_2 and Al_2O_3. The lack of slagging and of troublesome deposits experienced with the MIS when processing these materials demonstrates these good fusion characteristics of Al and Si.

AVAILABILITY

The availability of the incineration system was determined by several factors consisting of: the interaction of the various parts of the system with feed or ash characteristics, basic mechanical design factors, crew shakedown periods at the start of each operating period, and interruptions to perform scientific and regulatory tests. As the incineration of the contaminated materials progressed, adverse feed characteristics and deficiencies in the design and operation of the MIS were identified. Corrective actions were taken to deal with adverse feed characteristics and to remedy design deficiencies. These actions produced increases in the capacity and the reliability of the MIS and a significant reduction in

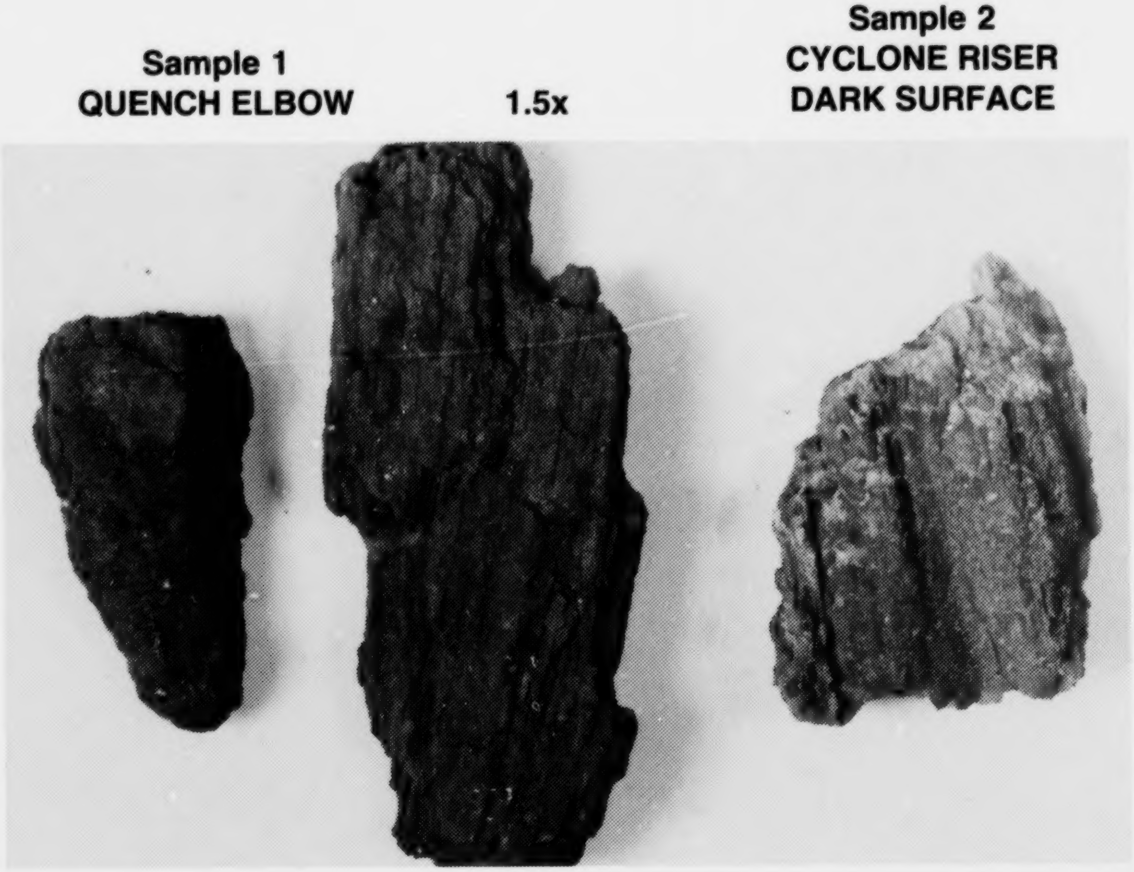

Sample 1
QUENCH ELBOW
1.5x
Sample 2
CYCLONE RISER
DARK SURFACE

Figure 27. Macrophotographs of deposits caused by brominated sludge from Quench Elbow (1) and Cyclone Riser Duct (2)

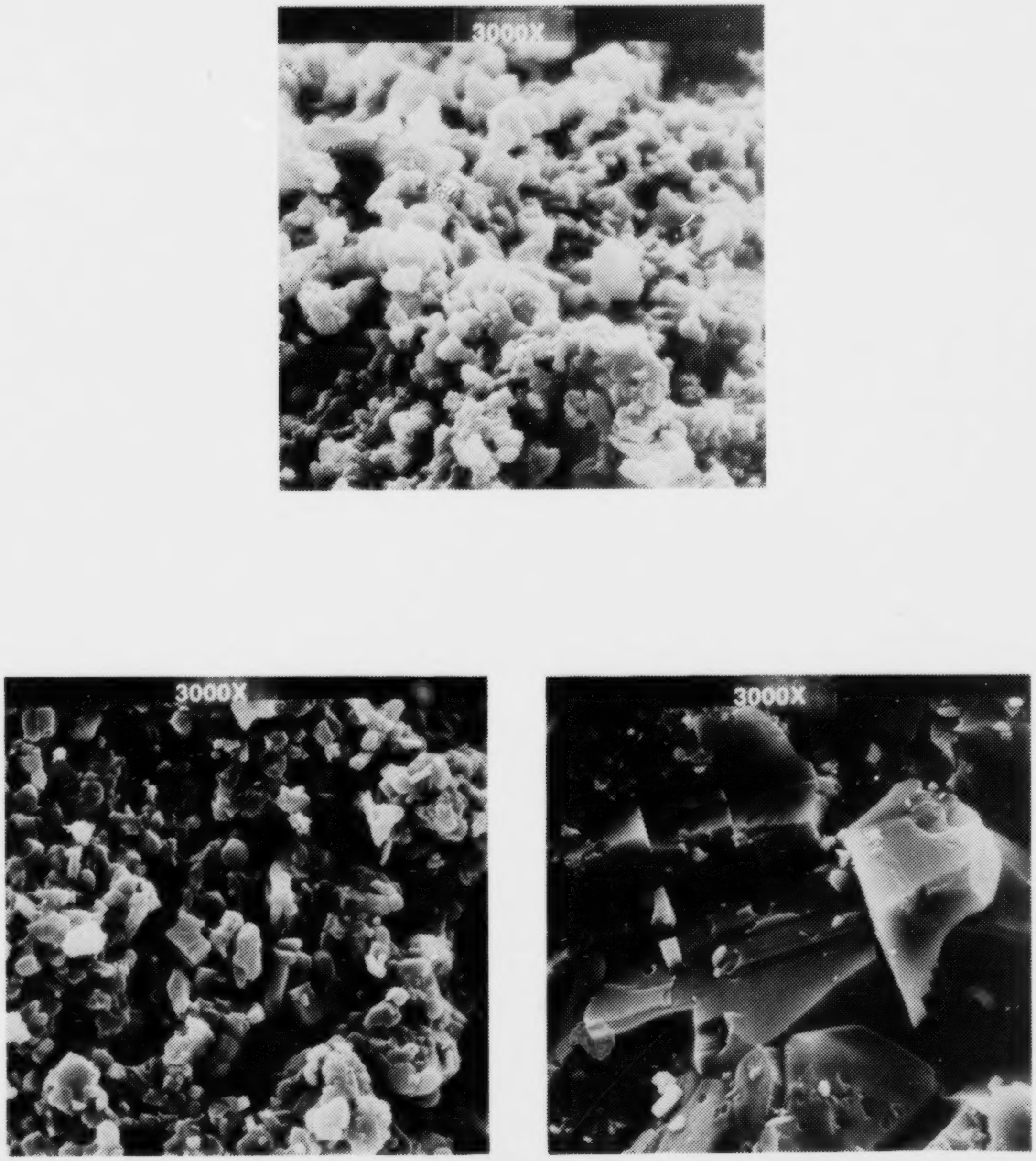

3000X
3000X
3000X

Figure 28. SEM photomicrographs of the cross section of the deposit from the Cyclone Riser Duct.

TABLE 52. RESULTS OF ASH DEPOSIT ANALYSIS FROM MIS CYCLONE RISER DUCT

Analyte		Reported as	Amount (wt%)	Analytical technique
Silicon	(Si)	Silicon Dioxide	25.6	X-ray
Aluminum	(Al)	Aluminum Dioxide	8.5	X-ray
Titanium	(Ti)	Titanium Dioxide	0.3	X-ray
Iron	(Fe)	Ferric Oxide	5.0	X-ray
Calcium	(Ca)	Calcium Oxide	36.7	X-ray
Magnesium	(Mg)	Magnesium Oxide	1.5	AA (a)
Sodium	(Na)	Sodium Oxide	0.4	AA (a)
Potassium	(K)	Potassium Oxide	0.4	X-ray
Sulfur	(S)	Sulfur Trioxide	21.0	X-ray
Phosphorous	(P)	Phos. Pentoxide	0.5	X-ray

(a) AA = Atomic Absorption Spectroscopy

operating costs. Figure 29 shows that the feeding time has increased from 40% to 80% of the total available time between 1985 and 1989.

Availability During 1985-1986

During 1985 the overall availability averaged 50% while processing materials from the first five sites. As shown in Table 53, this consisted of 38.1% (42% including liquids) for July and August when the unit was operated by International Technology (IT) Corporation and 54% (55% including liquids) for October to February when the unit was operated by Enviresponse Incorporated (EI). The chief cause of downtime was the buildup of solids in the SCC. Approximately 90% of the downtime was attributable to cleaning out the particulate carryover from the kiln to the SCC. Another source of downtime was extensive maintenance on the CHEAF. As explained in Section 3, the addition of the cyclone and the replacement of the CHEAF with the WEP were the major actions taken to address these concerns.

Availability During 1987

During the 14-week operation of the modified system, an overall system availability of 53% was achieved. This consisted of a 30.5% availability during the trial burn and a 54.8% availability during other activities.

Although slagging or plugging of the SCC was almost eliminated, the anticipated improvement in availability did not materialize. New sources of downtime or unavailability were encountered. The new causes of downtime were the slagging of the kiln that accounted for 10.6% and delays caused by testing and preparation for testing that caused 8.7%. Other important factors were mechanical failures accounting for 9.9%; and human error accounting for 7.4%. All causes of downtime are presented in Tables 54. The reasons for these periods of unavailability are discussed below.

Kiln Slagging --

Kiln slagging became a factor in 1987 due to the processing of large quantities of trash that constituted about 40% of the feed to the MIS. The trash present in the feed caused slagging of the kiln walls with a lava-type hard material that eventually built a dam restricting the flow of material through the kiln. The materials conducive to the slagging were plastic materials used to contain the contaminated dirt during transport to the site and the discarded clothing and material used during cleanup, such as rubber gloves, plastic suit material, boots, etc.
Prior to the modifications only small quantities of trash had been fed because of the difficulties encountered in processing it. Processing difficulties included inability to control

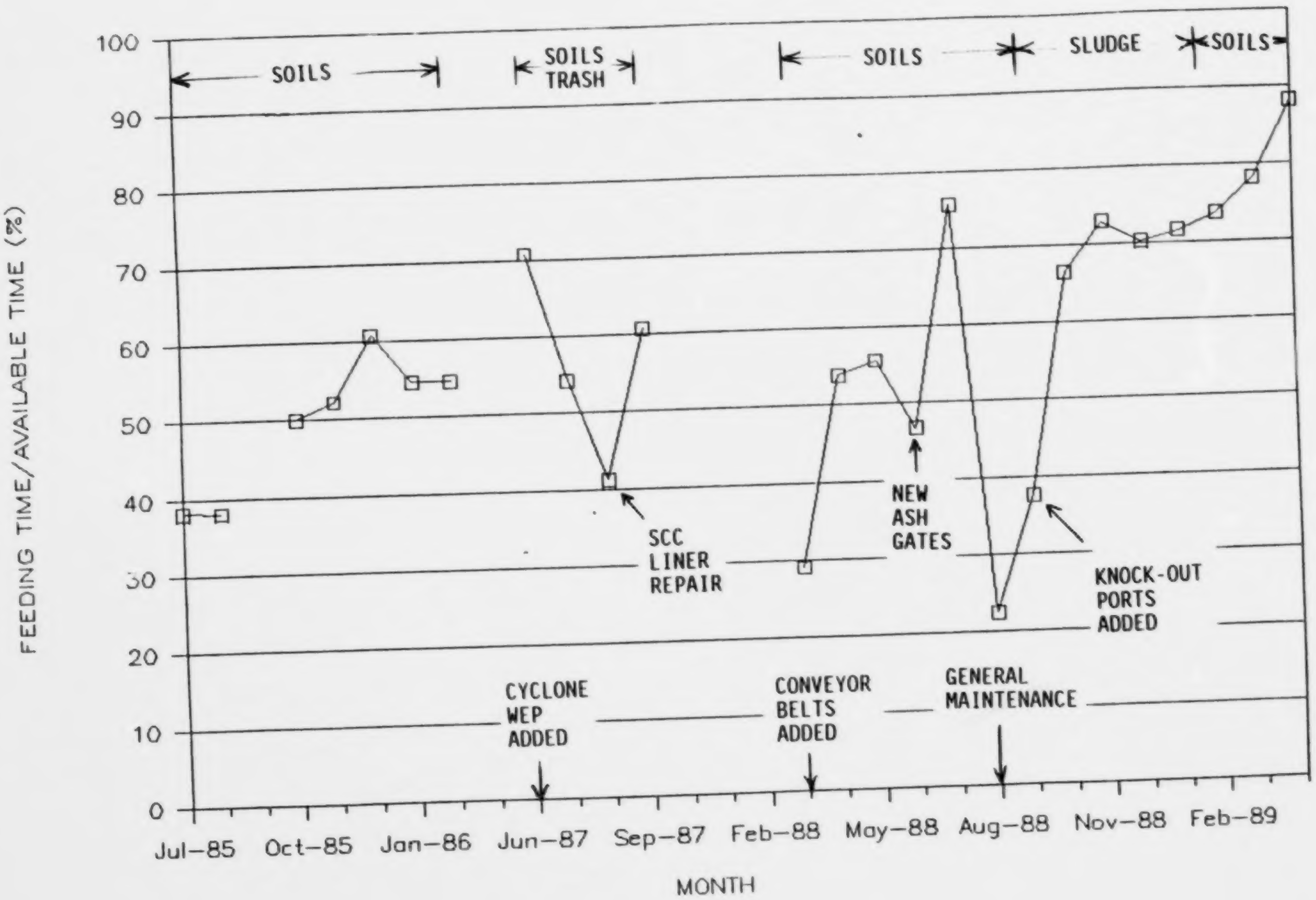


Figure 29. MIS availability.

TABLE 53. AVAILABILITY HISTORY OF THE MIS

Feed Source or Activity	Date of Activity	Hours Out	Hours Online	Total Hours	Avail.(a) (%)
1985-1986					
Neosho and The Farms(b)	7/23/85-8/27/85	591	363	954	38.1
Neosho and The Farms(b)	10/26/85-2/03/86	1313	1540	2853	54.0
1985-1986 Totals		1904	1903	3807	50.0
1987					
Neosho and The Farms(c)	6/12-9/18	995	1217	2212	54.8
RCRA/TSCA Trial Burn(d)	7/28-8/3 8/31-9/1	132	58	190	30.5
1987 Totals		1127	1275	2402	53.1
1988-1989					
Baldwin Park(e)	2/22/88-4/27/88	966	620	1586	39.1
Baldwin Park Trash(f)	8/02/88-8/12/88	104	149	253	58.9
Brominated Sludge Tests	4/28/88-5/01/88	35	43	78	55.1
Verona	5/02/88-8/01/88	891	1324	2215	59.8
Maintenance	8/12/88-8/31/88	453	0	453	0.0
Brominated Sludge	8/31/88-1/23/89	1331	2061	3392	60.8
Closure(g)	1/24/89-4/15/89	382	1530	1912	80.0
1988-1989 Totals		3709	5727	9436	60.7(h)

(a) % Availability =(Time Processing Solid Feed/Total Time) x 100.

(b) The Farms are Denney, Erwin, Rusha and Tally. Only small quantities of trash were processed.

(c) Approximately 475,000 lb of trash.

(d) The low availability was due to preparation time and a failed kiln bearing.

(e) The low availability was due to problems encountered during the start-up in February and March, 1988.

(f) Most of the material was trash consisting of wooden pallets and steel barrels.

(g) Due to decontamination of the feed system the records stop on April 15. Incineration activities continued until April 22, 1989, chiefly on residues from cleaning the feed system.

(h) Availability calculation excludes the August 1988 maintenance period.

TABLE 54. CAUSES OF SYSTEM UNAVAILABILITY IN 1987

Cause	Unavailability (%)
Testing Delays	6.6
Kiln Slagging	10.6
Feed Jamming	3.5
Mechanical	9.9
Electrical	2.3
WEP	4.6
Human Error	7.4
Maintenance (Demister^R Installation)	2.1
Total	47.0

kiln temperature and excess oxygen, and feed system jams. The modifications to the feed system and the addition of the oxygen burner system permitted the feeding of trash but slagging of the kiln then became a major reliability factor. The mechanism of slagging is discussed above under the topic Ash Fusion Characteristics.

Trash content of the feed also was the major causative factor for the 3.5% unavailability due to feed jamming. Hence, the feeding of excessive trash in the waste materials directly contributed 14% downtime.

Testing Delays --

Table 54 shows that 6.6% of the total unavailability was due to delays related to testing. These delays were associated with times required to clean out the system (kiln, conveyor, water system flush, etc.); to prepare for the tests; to hold on hot standby between tests; and to perform special calibrations.

The 2.1% unavailability due to maintenance primarily represents the downtime during the Demister^{R} installation. The installation of the mist eliminator was required for insuring success of the trial burn. Hence, it can be considered to be a special case of downtime associated with testing, which brings the total downtime related to testing up to 8.7%.

Mechanical Problems --

Mechanical problems caused 9.9% downtime. Most of the downtime associated with mechanical problems was caused by the failure of the Inconel^{R} 625 venturi at the exit of the SCC. The unavailability associated with this part was 6.3% as shown in Table 55. The other major mechanical problem was the replacement of the ripped conveyor belt, which caused 1.9%.

Human Error --

Human error caused 7.4% of the unavailability. This consisted of the time to decontaminate the process water system when it became contaminated with furans. The story of this furan contamination is given in Section 6.

WEP Problems --

The WEP caused 4.6% downtime as follows: It was difficult to establish the required high voltage during initial startup of the precipitator. The electrodes had to be positioned accurately within each box cell before voltage could be sustained without breakdown. After a hot cycle, the WEP again failed to hold high voltage because of electrode shorting. The electrodes were again adjusted and reinforcing angles were

TABLE 55. UNAVAILABILITY DUE TO MECHANICAL FAILURES IN 1987

Mechanical Item	Unavailability (%)
Venturi at SCC exit	6.3
Conveyor belt	1.9
Kiln bearing	0.5
Quench tank pump	0.5
Hydraulic hose	0.4
Kiln seal breakage	0.3
Total	9.9

added to the rod suspension system. The unit performed normally for 20 days, and then all three circuit boards failed in the control panel catastrophically. This caused a three-day shutdown until new replacement circuit boards could be installed. No conclusive reason could be established for the failure, but metal chips from the initial cabinet assembly were thought to be the cause. After replacing the boards and turning off the fogging sprays, the unit sustained satisfactory operation. It has been necessary to perform a wash cycle daily or more often in heavy feed conditions to maintain high voltage. This wash cycle removes particulate buildup from the surfaces of box cells.

The fiberglass rods also were subject to a rupture failure mode that occurred after repeated short cycles. To overcome both the rod movement problem and the rupture failure problem, the rod material was changed to Type 304 stainless steel. The stainless steel rods were installed in the unit during September 1988. They have solved the rupture problem.

Availability During 1988 and 1989

During 1988 and 1989, the availability of the unit averaged 61%. This period was marked by constant improvement in the availability, because many problem areas such as the SCC venturi nozzle, the kiln ash gates, the WEP rod failure problem, the pH control system, the diesel fuel delivery system and the spare parts inventory were addressed. As shown in Figure 29, availability of the MIS exceeded 70% from November 1988 until the end of Closure. The 70% level was exceeded even though the unit was processing brominated sludge, which had a tendency to foul flue gas passages and instruments.

The unavailability data can be approached both from the perspective of the major components or systems of the MIS associated with the downtime and from the perspective of the type of failure. These approaches give different insights into the problems associated with availability. This report will first discuss availability in terms of the systems using Tables 56 and 57 as references. Following this discussion, the report will discuss availability in terms of the types of failure using Tables 58 and 59 as references. Since each feedstock affected the MIS differently, the causes of downtime will be discussed for each incineration activity separately.

Systems Viewpoint of Availability

The systems viewpoint of availability shows which part of the MIS contributed most to the downtime. As shown in Table 56, problems associated with the kiln produced the greatest downtime during 1988-1989. The 12.9% downtime

TABLE 56. SYSTEM SOURCES OF MIS UNAVAILABILITY
1988-1989

Feed Source or Activity	Cumulative Downtime by MIS System Expressed as % Downtime										
	Instr. Air	All	APC	Ash	Ducting	ID Fan	Feed	Kiln	Quench	SCC	Total Unavail.
Baldwin Park	0.06%	2.27%	9.52%	0.57%	0.00%	0.00%	7.69%	28.75%	0.69%	11.35%	60.91%
Baldwin Park Trash	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.58%	39.53%	0.00%	0.00%	41.11%
Scoping Burn	0.00%	55.13%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	44.87%
Verona	0.09%	6.68%	0.41%	0.63%	0.00%	5.51%	6.85%	30.23%	0.60%	9.79%	40.23%
Maintenance	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Brominated Sludge	4.35%	0.68%	1.36%	0.21%	12.91%	1.87%	1.45%	10.18%	3.23%	3.17%	39.40%
Closure	0.37%	3.45%	0.00%	0.05%	4.71%	0.00%	7.27%	2.56%	0.00%	1.57%	19.98%
Average by System	1.59%	7.69%	2.08%	0.31%	5.31%	1.87%	3.92%	12.91%	1.28%	5.08%	

TABLE 57. SOURCES OF MIS UNAVAILABILITY BY SYSTEM AND BY HOURS
1988-1989

	Cumulative Downtime by MIS System										
System Feed Source or Activity	Instr. Air	All	APC	Ash	Ducting	ID Fan	Feed	Kiln	Quench	SCC	Total Unavail.
Baldwin Park	1	36	151	9	0	0	122	456	11	180	966
Baldwin Park Trash	0	0	0	0	0	0	4	100	0	0	104
Scoping Burn	0	35	0	0	0	0	0	0	0	0	35
Verona	2	148	9	14	0	122	74	329	7	186	891
Maintenance	0	453	0	0	0	0	0	0	0	0	453
Brominated Sludge	147	23	46	7	436	63	49	344	109	107	1331
Closure	7	66	0	1	90	0	139	49	0	30	382
Total By System	157	761	206	31	526	185	388	1278	127	503	4162

TABLE 58. SOURCES OF MIS UNAVAILABILITY BY TYPE AND PERCENTAGES
1988-1989

	Cumulative Downtime %										
Feed Source or Activity	Mech.	Feed Jamming	Ash Jamming	Elect.	Human	Slagging Kiln	Instr.	Slagging SCC	Testing	Maint.	Fouling
Baldwin Park	28.88%	0.25%	0.25%	2.65%	2.21%	16.33%	10.28%	0.06%	0.00%	0.00%	0.00%
Baldwin Park Trash	0.79%	0.40%	0.00%	0.00%	0.00%	37.55%	2.37%	0.00%	0.00%	0.00%	0.00%
Scoping Burn	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	44.87%	0.00%	0.00%
Verona	14.04%	0.00%	0.00%	0.54%	0.99%	17.16%	0.90%	0.00%	0.00%	6.59%	0.00%
Maintenance	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%
Brominated Sludge	8.28%	0.59%	0.03%	1.74%	0.18%	8.11%	2.71%	1.68%	0.00%	6.49%	9.43%
Closure	7.01%	2.41%	0.00%	0.58%	0.00%	0.00%	0.42%	0.00%	0.00%	3.40%	6.17%
Average by Type	11.99%	0.72%	0.05%	1.25%	0.63%	10.20%	2.92%	0.59%	0.35%	8.94%	4.43%

TABLE 59. SOURCES OF MIS UNAVAILABILITY BY TYPE AND HOURS
1988-1989

	Cumulative Downtime										
Feed Source or Activity	Mech.	Feed Jamming	Ash Jamming	Elect.	Human	Slagging Kiln	Instr.	Slagging SCC	Testing	Maint.	Fouling
Baldwin Park	458	4	4	42	35	259	163	1	0	0	0
Baldwin Park Trash	2	1	0	0	0	95	6	0	0	0	0
Scoping Burn	0	0	0	0	0	0	0	0	35	0	0
Verona	311	0	0	12	22	380	20	0	0	146	0
Maintenance	0	0	0	0	0	0	0	0	0	453	0
Brominated Sludge	281	20	1	59	6	275	92	57	0	220	320
Closure	134	46	0	11	0	0	8	0	0	65	118
Total By System	1186	71	5	124	63	1009	289	58	35	884	438

accounted for about 30% of the total MIS unavailability. The second largest category was downtimes that affected the total system. These included periods for general system maintenance and the testing periods. The 7.7% downtime affecting the total system accounted for about 18% of the unavailability. The duct system caused 5.3% downtime, which accounted for about 13% of the unavailability. The SCC caused 5.1% downtime, which accounted for 12% of the unavailability. The feed system caused 3.9% downtime, which accounted for 9% of the unavailability. By examining the distribution of these downtimes over different incineration activities, it is possible to determine which problems are feed related and which problems occur regardless of feed. As discussed below the downtime associated with the kiln was increased by feeds containing large amounts of trash. These increased the growth of slag deposits. The downtime associated with the duct system was caused by the brominated sludge, which formed a lightly sintered deposit in the ducts, in the cyclone, and at the exit of the SCC.

Baldwin Park --

The Baldwin Park incineration activities were divided into two periods: (1) February through April 1988, in which soil and trash were incinerated; and (2) August 2 through August 12, 1988, in which mainly trash was incinerated. The first period was characterized by only 39.1% availability. As shown in Figure 29 most of the problems occurred in the first month of operation. This month had only 29% availability. The second and final month of operation had 53.8% availability, which corresponded to previous values. The second period availability was an improved 58.9%.

During the troublesome first period, the kiln contributed 28.8% downtime; the SCC, 11.4%; the air pollution control (APC) system, 9.5%; and the feed system 7.7%. Much of the downtime associated with the kiln was caused by refractory repairs of the front face piece. Slagging caused most of the remaining downtime associated with the kiln. Almost all of the downtime associated with the SCC was caused by refractory repairs to a large section. The downtime associated with the APC system was caused by computer difficulties and a malfunctioning CO instrument. Feed system downtime was mainly caused by loss of hydraulic hoses associated with the shredder and conveyor belt motor failures.

Most of the above problems were of the types that do not recur frequently after the repairs are completed. This was substantiated during the next 9000 hours of operation when these failures did not recur.

During the second period, the 39.5% downtime contributed by the kiln, was almost all of the downtime. Most of this downtime, 37.6%, was caused by slagging. The slagging was related to the incineration of trash materials.

Scoping Burn --

All of the downtime for the scoping burn was associated with the testing to prove the feasibility of burning brominated sludge. Since this was a short test, it had a very minor affect on the availability of the MIS.

Verona --

The incineration of the soil and trash from Verona achieved an availability of 59.8%. This included an availability of 75.7% during July. The kiln contributed an unavailability of 14.9%; the SCC, 8.4%; all systems (general maintenance), 6.7%; the ID fan 5.5%; and the feed system, 3.3%.

The kiln downtime was caused mainly by slagging. Much of this slagging occurred in June due to problems with the ash gates as follows. The ash gates had warped and did not close properly. The failure to close permitted excessive air leakage that cooled the flue gases at the exit of the kiln. Since the control thermocouple for the kiln was downstream of the leakage point, it read an estimated 300°F to 400°F lower than the average gas temperature in the kiln. This caused the kiln burners to fire harder to achieve the setpoint temperature. Consequently, the kiln operated several hundred degrees higher than required. This increased the rate of slagging, so that the MIS was unavailable about 37% of June due to slagging.

Other causes of downtime were as follows. The SCC downtime was caused by failure of the SCC venturi. Downtime attributed to all systems was due to general maintainence on the unit prior to the start of the Verona campaign. The ID fan failures were caused by failure of a water pump and the diesel motor. Feed system downtime was caused by jamming of the main discharge conveyor and mechanical problems with the other conveyors.

Brominated Sludge --

The availability of the incinerator for brominated sludge was 60.8%. This is increased to 66.8% if the month of September is excluded. The unit had only a 37.6% availability in September because the brominated sludge caused fouling problems, which were addressed by shutting the unit down and adding cleanout ports in the ductwork. The cleanout ports were necessary during incineration of the sludge because of the continuous fouling of the duct work. Duct cleanouts, which lasted a few hours, occurred almost daily using these ports. Operations would have been extremely difficult without them. The sources of downtime for brominated sludge were the duct system, 12.8%; the kiln, 10.1%; the instrument air system, 4.3%; the quench, 3.2%; and the SCC, 3.1%.

The changed pattern for downtime reflected the ash characteristics of the brominated sludge. This material contained large quantities of fine material, which formed a lightly sintered deposit that would clog the ducts between the kiln, cyclone and SCC, and the exit of the SCC. Most of the kiln downtime was caused by slag formation. The instrument air system downtime was caused by air compressor failure and consisted of the time required to filter the process water as a precaution against contamination. Quench system and SCC downtimes were associated with the ash characteristics.

Closure --

The availability during the closure period was a record 80%. The sources of downtime were the feed system, 7.27%; the duct system, 4.71%; and all systems, 3.45%. The main cause of the feed system downtime was a worn conveyor belt. This would have been replaced if the MIS was scheduled for further usage at Denney Farm. Duct system downtime was caused by fouling of the cyclone. The downtime attributed to all systems was due to general maintenance on the unit.

Availability and Types of Failure

Examining availability from the viewpoint of the type of failure gives a different perspective. This data is presented in Tables 58 and 59. From this perspective, the main type of failure was mechanical failures, which accounted for 11.99% downtime. Slagging incidents accounted for 10.8% downtime; general maintainence, 8.94% downtime; fouling by fly ash, 4.43%; instrument problems, 2.92%; electrical problems, 1.25%; and all other sources, 2.35%.

Mechanical Problems --

Mechanical problems were most prevalent during the start-up period for Baldwin Park. Problems such as refractory loss from the front face of the kiln (112 hr) and the SCC (145 hr) caused about half of the 28.9% mechanically caused downtime from this period. The Verona campaign was marked by failures of the ID fan (122 hr) and the SCC venturi (79 hr) which caused about two thirds of the 14.04% downtime. After the Verona campaign mechanical problems were greatly reduced; this was partially due to design changes such as a new refractory SCC venturi; better pH control, which reduced process piping corrosion; and a greater spare parts inventory obtained in September 1988.

SCC Venturi Redesign - The original SCC was completely lined with refractory, except for the exit venturi and diffuser, which are made of Inconel^{R} 625. After over 3000 hr of operation, some of which was with highly chlorinated compounds, the exit venturi had completely disintegrated, and its support plate showed severe stress corrosion cracking.

Based upon the presence of chlorine in conjunction with the high temperature (2200°F), the material for the venturi and diffuser was changed to Haynes^R alloy 556. The change to this material failed to extend the life of these parts. Finally, the parts were refabricated using refractory. By the time MIS operations were shut down, the refractory venturi had operated over 5000 hours without problems.

pH Control Improvement - During 1987 the MIS experienced difficulty in controlling the pH in the process water system. Corrosion in the process water system was attributed to excursions when the process water became acidic for brief periods of time. The pH control was improved in stages starting with changes in 1987. The nature of the problem and the steps taken to solve it are described below.

The scrubber system for the MIS utilized a caustic solution to neutralize the HCl gas formed and to maintain the scrubber water pH in the 7 to 9.5 range. There were three areas in the MIS where the flue gas was scrubbed:

- Quench elbow and sump
- Lower WEP filler region
- Mass transfer (MX) scrubber

A 10% to 20% caustic solution was injected into the quench sump and into the recirculation water flow of the MX scrubber. The initial and largest percentage of the neutralization occurred in the quench elbow and sump. For that reason the majority of the caustic had to be injected at this location. The injection of caustic directly into the quench system tank from a line controller by a solenoid valve located 25 feet upstream caused large swings in the pH (3-10.5) of the quench sump. The long injection line between the valve and the quench sump caused an initial delay in caustic injection after the valve was activated. The pH continued to decrease during this delay. After the valve was closed the line caused an uncontrolled trail-off of injection. The pH continued to rise during the trail-off. The swings could be controlled for any one condition of organic chloride loading by changing the setting of the timer. However, when organic chloride loading changed sharply, the timing required manual changes. Also, under heavy loadings the swings were still excessive. In 1987, the caustic injection valve was placed at the quench sump to eliminate the delays. This reduced the uncontrolled swings but did not completely solve the problem. Further steps were necessary as described below.

The pH was controlled with pH sensors which operated in slip streams from the recirculation water loops. These sensors fouled easily and required frequent cleaning to keep them functional. The sensors were also suitable for only on/off control of the caustic solution.

In 1988, the system was changed to modulating control using a Great Lakes^R unit, which also featured a flow-through sensor. This change produced smooth control of the pH, and the flow-through sensors were resistant to fouling. Hence, control was improved and maintenance on the instrumentation and the process water system was decreased.

Spare Parts Inventory - During 1988, a study was performed which identified critical spare parts. These parts were purchased and put into inventory. The spare part inventory prevented the downtime that was sometimes associated with waiting for a critical spare part to arrive. This arrangement could save anywhere from an hour to one or two days of time.

Slagging Problems --

As described previously, the slagging problems were greatest when burning trash as shown by the 37.6% downtime (95 hr) for the Baldwin Park trash. Although slagging was still a factor, downtime caused by it decreased dramatically for the brominated sludge and closure campaigns. This improvement was due to both redesigned ash gates, which reduced air inleakage and permitted more accurate kiln temperature measurements, and lower percentages of trash in the feed.

In addition to the above factors, slagging rates were also minimized by operating practices. The kiln temperature setpoint was kept low - 1450°F for soils. Also, trash was blended with maximum amounts of soil to provide a heat sink that would prevent formation of hot spots in the solid matrix and to dilute slag forming elements such as sodium. Dilution of these elements increases the temperature at which slag forms.

Maintenance --

Before each campaign and during some campaigns, the incineration system was shut down for a period of general maintenance. Work performed during these periods consisted of addition of hardware improvements; repair of refractory damage; cleaning of the kiln, ductwork, SCC, quench, and other components of deposits; and preventive maintenance. This work accounted for about 9% of the downtime.

Fouling --

Fouling consisted of: deposits that restricted the flow areas in the duct system, the cyclone, and the quench elbow; deposits that fouled the thermocouples, the kiln oxygen analyzer, and other instrumentation; and sedimentation that filled the quench sump and the CPI separator. The rate of fouling was highly dependent on the ash characteristics of the feed materials. For brominated sludge fouling caused 9.4% downtime (320 hr) but for most feed materials fouling was controlled by the cleaning of the system during the general maintenance periods. The installation of clean out ports in the duct system was a necessary action to minimize the downtime caused by the ash from brominated sludge.

Instrument Problems --

Instrument problems accounted for 2.9% downtime. These consisted of instrument failures such as the CO analyzer failure, weigh scale failures, broken thermocouples, etc. Instrument problems were highest immediately after start-up during the Baldwin Park campaign. Instruments contributed 10.3% downtime (163 hr) during this period. Much of this downtime (88 hr) was caused by failure of the CO analyzer and computer problems in the analytical trailer. After the Baldwin Park campaign, instrument problems occurred when the unit was processing difficult feeds such as brominated sludge or trash. When the unit was processing soil, instrument problems were minimal.

Electrical Problems --

Electrical problems caused only 1.3% downtime. Conveyor belt motor problems caused 31 hours; shorting of the WEP control panel caused 35 hours. All other electrical problems were of short duration.

Feed Jamming --

Downtime caused by feed jamming averaged only 0.7% during the 1988-1989 processing period. This was a great improvement over the 3.5% downtime experienced in 1987. This improvement was achieved by replacing the doctor blade at the exit of the feed hopper with a roller and by manual preparation of feed material that was troublesome to shred.

The 2.4% downtime experienced during the closure period was caused by a worn conveyor belt that permitted feed material to flow over the side. This material would then block the conveyor and prevent it from operating.

SECTION 9

DENNEY FARM SITE AND MIS CLOSURE

CLOSURE PLANS AND CLEANUP CRITERIA

After the MIS had completed incineration of the dioxin-contaminated materials from the eight sites, the MIS was closed by executing approved closure plans [9, 30]. Because incineration activities and site activities were conducted by different parties and were covered under two separate permits, two separate approved closure plans were required by the regulatory authorities, one for the MIS and one for the site. The closure of the MIS followed the plan presented in the 1987 final permit [9]. The closure procedures for the MIS were updated by adding greater detail to the plan presented in the permit. These details were included in the final closure plan for the Denney Farm site [30]. Besides procedures for decontaminating and decommissioning the MIS, the site closure plan included sampling procedures for soil, buildings and equipment, scope of the decontamination work, and action levels to trigger decontamination work.

Closure of the MIS and Denney Farm site, which took place from January 24, to June 30, 1989, involved decontamination of the MIS, Denney Farm soil, and supporting equipment and buildings. The cleanup criteria for the MIS and the site, which were included in the final site closure plan [30], are presented in Table 60. The Agency for Toxic Substances and Disease Registry provided health advisories used to develop these criteria, and the criteria were approved by MDNR.

CLOSURE SUMMARY

Closure activities included excavation and incineration of dioxin-contaminated soil, decontamination or incineration of contaminated debris, decontamination of buildings and equipment, and disassembly of buildings and the MIS. Closure activities are summarized below.

Almost 3,000,000 lb of dioxin-contaminated soil and debris were incinerated. The debris included: the loading dock, HEPA filter and associated ducting, wooden pallets, metal drums, and plastic sheeting used to protect excavated areas. The four buildings in the hot zone, which were constructed of sheet metal walls, wooden supports, and concrete foundations, were decontaminated. The following equipment was decontaminated: the four rented pieces of soil moving equipment used in the hot zone, including a backhoe, a forklift, and two small front-end loaders (Bobcats^R); and the MIS feed system, consisting of three feed conveyors, the

TABLE 60. ACTION LEVELS OR CLEANUP CRITERIA FOR DENNEY FARM CLOSURE

Contaminant	Surface Soils (0 to 3 in. depth)	Subsurface Soils (>3 in. depth)	Buildings(a) (Wood Framework/Sheet Metal Siding/Foundations)
2,3,7,8-TCDD	<1 ppb	<10 ppb + 12-in soil cover or maximum 4-ft excavation + 4-ft soil cover	10 ng/m^2 (1 pg/cm^2) or >10 ng/m^2 + Sealant
PCBs	<2 ppm	<10 ppm + 12-in soil cover	100 ng/cm^2 or >1 ug/cm^2 + Sealant
Volatile/ Semivolatile	<50 ppm	<50 ppm	no significant contamination
Heavy Metals	non-E.P. Toxic	non-E.P. Toxic	no significant contamination

(a) Foundations had an additional criterion. Core samples were taken and the dust from the samples was analyzed and had to show concentrations of 2,3,7,8-TCDD <10 ppb.

shredder, weigh chute, weigh scale, ram, ram trough, and Hapman^R conveyor. The rubber conveyor belts were incinerated as part of the decontamination process.

Equipment located outside the hot zone was cleaned and wipe tested to ensure that it was not contaminated. Wipe testing of the MIS building located outside the hot zone showed that the walls were not contaminated. However, the floor beneath the feed system had to be decontaminated. The 17 pieces of rental equipment located in the safe zone, consisting of two air compressors, eight trailers serving as offices and crew quarters, four storage trailers for spare parts and other materials, and three frag tanks for wastewater storage, were cleaned and wipe tested. The MIS equipment was also cleaned and wipe tested. This equipment included the three trailers on which the major components of the MIS were mounted, the air pollution monitoring trailer, HEPA trailer, electric generators, Monarch^R CPI separator, cyclone, WEP, air dryer, water softener, four wastewater storage tanks, process water storage tank, caustic storage tank, three discharge water holding tanks, and several pumps.

Final MIS closure activities consisted of dismantling the unit and preparing its components for shipment and storage at the EPA facility in Edison, New Jersey. Final Denney Farm closure activities included disassembly of the buildings and final grading of the site. The site was covered with a minimum of one foot of soil and seeded. Closure of the MIS and site were certified by an independent professional engineer registered in the State of Missouri.

SOIL, BUILDING AND EQUIPMENT DECONTAMINATION

The extent of contamination was determined through preclosure sampling and analysis conducted in November and December 1988. Soil samples, samples from various parts of the buildings, and samples from the equipment were taken and analyzed to determine the extent of contamination resulting from activities at the site. The samples were analyzed using approved SW Methods for dioxins/furans, PCBs, organics, and metals. The results of the analyses were compared with the action levels for the site presented in Table 60.

Soil Sampling and Decontamination

Sampling was conducted prior to the start of site closure activities to determine the extent of contamination of the site soil. This sampling and analysis was primarily for dioxin using a statistical procedure to guarantee that the dioxin levels reported were within 95% confidence limits [31]. This means that there is less than a 5% chance that the actual concentration exceeds the maximum concentration obtained from the statistical analysis of the analytical results. In addition, grab samples were taken and analyzed for dioxin and the other constituents listed in Table 60. The results of this sampling are presented in Tables 61 and 62. The sample locations are depicted on Figure 30.

The sampling and analysis method for dioxin referenced above is described below. The site is divided into sections. Each section is divided into 50 equal areas, and three aliquots are taken from each area. The aliquots taken correspond to locations 2, 4, and 5 as shown in Figure 31. The 50 aliquots from location 2 are composited to form one sample. The same is done for the aliquots from location 4 and location 5. Therefore, a total of three composite samples are analyzed. The results of the three composite samples are combined statistically to arrive at the 95% confidence limit for the section (see footnote 1, Table 61).

The preclosure sampling at Denney Farm for dioxin was executed by dividing the site into 16 sections of approximately 5000-ft^2 areas consisting of 6 sections inside the hot zone and 10 sections outside the hot zone as shown in Figure 30. Dioxin contamination was found in the hot zone as expected and was also found in the 10 outside sections. At the beginning of closure activities in January 1989, the 10 outside sections were divided into 2400-ft^2 sections to further delineate the dioxin-contaminated area (Figure 32). In addition, another 16 sections outside the hot zone were added during the closure process to determine the extent of the contamination. The final allocation of areas with their levels of contamination is shown in Figure 32. The areas with dioxin concentrations greater than the action level were designated as contaminated areas and were targeted for remediation.

Contaminated soil was scraped in layers of at least three inches and incinerated. After each scraping, the underlying soil was sampled and analyzed for dioxin. Dioxin was selected as the indicator chemical for the soil decontamination/excavation process due to its prevalence at the site and the stringent action level for it. Scraping and incineration continued until sampling and analysis showed that the contamination of the remaining soil was below the action level for dioxin. Once an area was below the dioxin action level, it was sampled and analyzed for the other constituents listed on Table 60. Decontaminated areas were covered temporarily with plastic sheeting to prevent the spread of contamination from contaminated areas until the excavation was completed and the entire site was covered with

TABLE 61. INITIAL PRECLOSURE SOIL SAMPLING RESULTS [November 1988]

Section No.	Sampling Date	2,3,7,8-TCDD(a) (ppb)	Chromium(b) (ppm)	PCBs(c) (ppm)
Perimeter Sections(d)				
1 SW	11-7-88	7.69	16	160
2 SE	11-7-88	1.14	11	ND
3 NE	11-7-88	5.33	19	ND
4 NW	11-7-88	5.10	13	ND
5 Ash Storage	11-7-88	2.94	200	ND
Hot Zone Sections				
6 SW	11-7-88	127.44	30	240(e)
7 NW	11-7-88	659.00	4.7	40(f)
8 SW-NE	11-7-88	227.37	8.5	16
9 Trench	11-7-88	16.77	13	190
10 NE	11-8-88	7.75	7.8	1.6
11 SE	11-8-88	6.68	15	ND

(a) All 2,3,7,8-TCDD concentrations are at the 95% Upper Confidence Limit (UCL):

$C_i = \bar{X} + 2.92\ S/1.731$

where:

$\underline{C}_i$ = Maximum concentration of contamination at 95% UCL.

$\bar{X}$ = Mean concentration of three composite samples.

S = Standard Deviation of three composite samples.

(b) Chromium is total chromium not EP toxicity chromium. The levels detected were considered to be safe.

(c) PCBs expressed as Aroclor-1260.

(d) SW=southwest, NW=northwest, SE=southeast, NE=northeast.

(e) Also contained 200 ppm tetrachlorobenzene and 30 ppm hexachlorophene.

(f) Aroclor-1016.

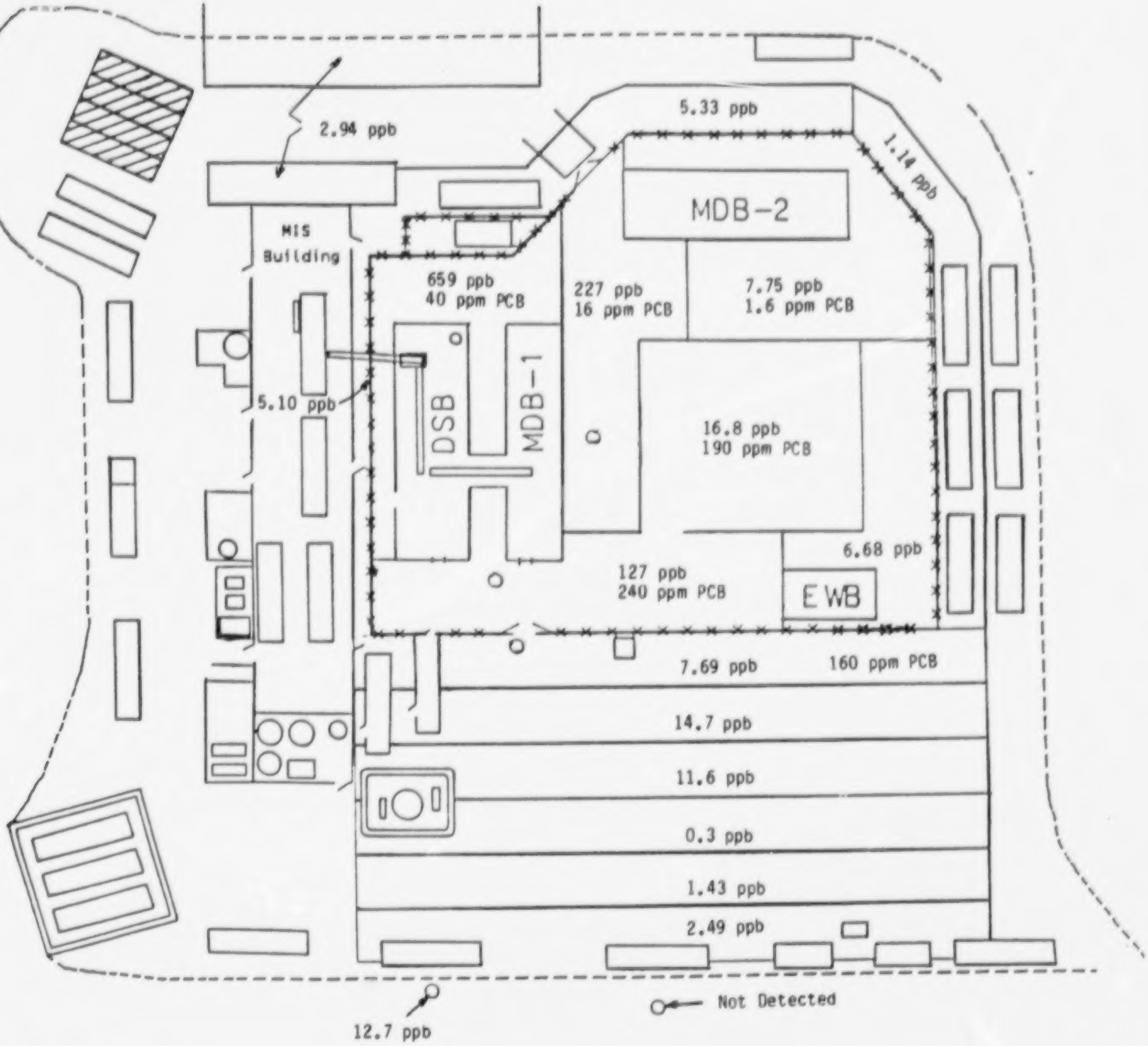
Note: Other organics were detected at low levels (<10 ppm).

Action levels: See Table 60.

TABLE 62. FOLLOW-UP PRECLOSURE SOIL SAMPLING RESULTS [December 1988]

Sample Type	TCDD Concentration (ppb)
I. 95% UCL Soil Samples (0 to 2 in.)	
1. Section 12	14.69
2. Section 13	11.61
3. Section 14	0.31
4. Section 15	1.43
5. Section 16	2.49
II. Depth Samples in Section 1(a)	
1. 0 to 3 in.	10.49
2. 3 to 6 in.	3.00
3. 6 to 9 in.	3.06
4. 9 to 12 in.	ND**
III. Depth Samples in Section 6(a)	
1. 0 to 3 in.	119.66
2. 3 to 6 in.	3.21
3. 6 to 9 in.	3.51
IV. Depth Samples in Section 8(a)	
1. 0 to 3 in.	10.13
2. 3 to 6 in.	2.01
3. 6 to 9 in.	0.67
4. 9 to 12 in.	1.25
V. Grab Samples in Section 7 (0 to 2 in.) (10 aliquots each)	
1. Around waste oil containment	11.23
2. Underneath HEPA duct	8.23
3. Between MDB-1 and DSB	3798
VI. Wooded Area South of Trailers (0 to 2 in.) (5 to 7 aliquots)	
1. Soils south of the site	ND(b)
2. Runoff behind trailer #5	12.74

(a) Grab samples
(b) ND = not detected


2.94 ppb
5.33 ppb
1.14 ppb
MDB-2
MIS Building
659 ppb
40 ppm PCB
227 ppb
16 ppm PCB
7.75 ppb
1.6 ppm PCB
5.10 ppb
DSB
MDB-1
16.8 ppb
190 ppm PCB
6.68 ppb
127 ppb
240 ppm PCB
EWB
7.69 ppb
160 ppm PCB
14.7 ppb
11.6 ppb
0.3 ppb
1.43 ppb
2.49 ppb
12.7 ppb
Not Detected

-x-x-x- Hot Zone Fence
DSB Drum Storage Building
MDB-1 Hazardous Waste Storage Building
MDB-2 Hazardous Waste Storage Building
EWB Equipment Washdown Building

o Grab Sample Location (See Table 62)

Data = 2,3,7,8-TCDD concentrations

PCB = PCB concentrations

Figure 30. Denney Farm Site Preclosure Sampling Results
November and December 1988

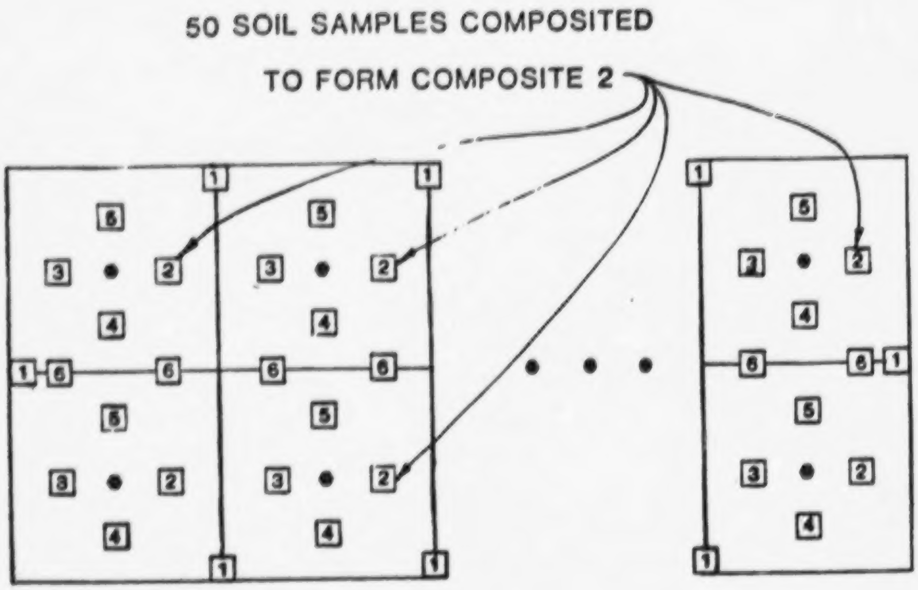
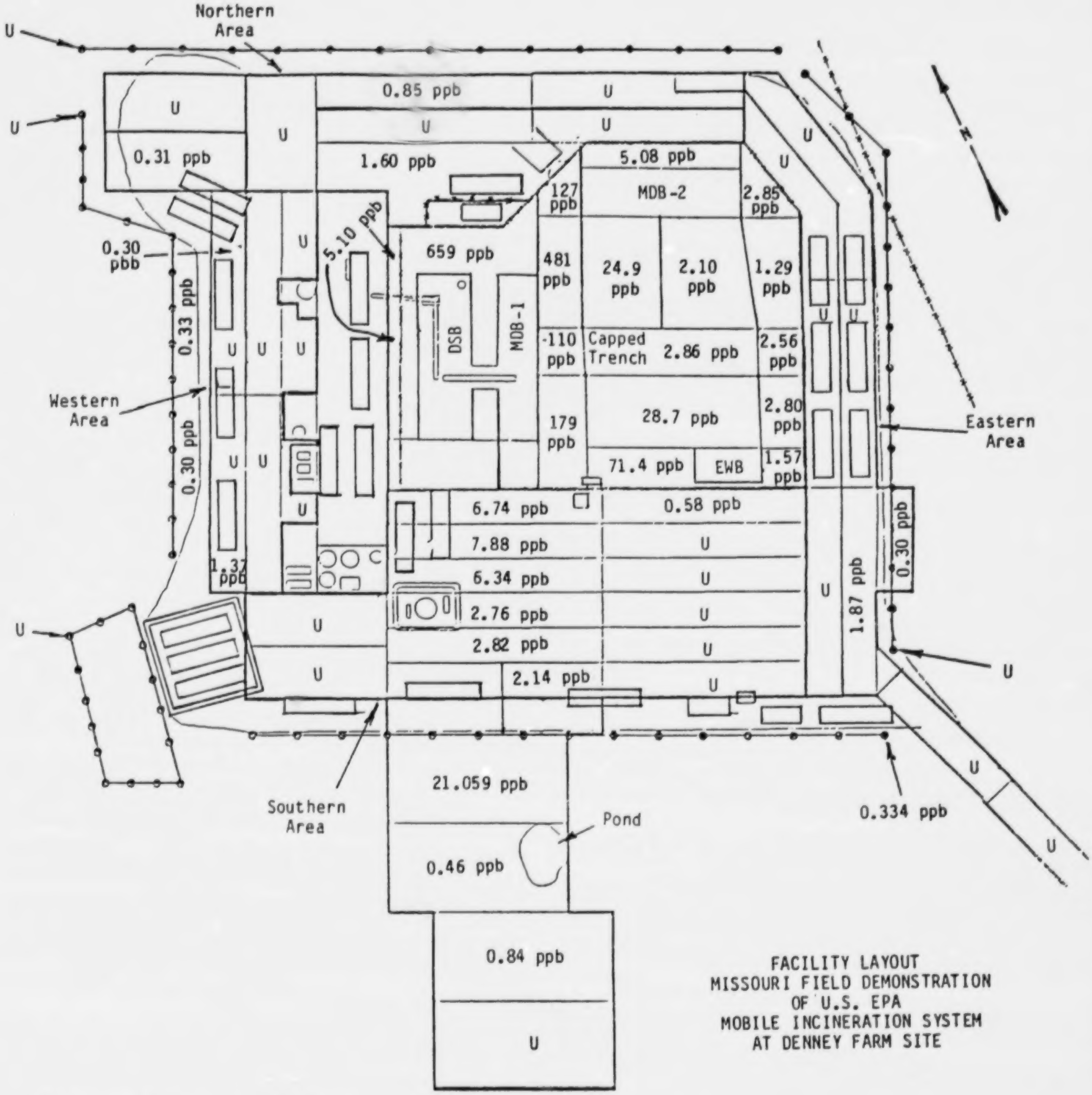

50 SOIL SAMPLES COMPOSITED
TO FORM COMPOSITE 2
1
2
3
4
5
6

Figure 31. Systematic Sampling Design for Obtaining the 3 Composite Samples.


Northern Area
U
0.85 ppb
U
U
U
U
0.31 ppb
U
1.60 ppb
5.08 ppb
127 ppb
MDB-2
2.85 ppb
U
U
N
0.30 pbb
U
5.10 ppb
659 ppb
481 ppb
24.9 ppb
2.10 ppb
1.29 ppb
0.33 ppb
U
U
U
DSB
MDB-1
U
U
-110 ppb
Capped Trench
2.86 ppb
2.56 ppb
Western Area
179 ppb
28.7 ppb
2.80 ppb
Eastern Area
0.30 ppb
U
U
71.4 ppb
EWB
1.57 ppb
U
6.74 ppb
0.58 ppb
0.30 ppb
7.88 ppb
U
1.37 ppb
6.34 ppb
U
U
1.87 ppb
U
U
2.76 ppb
U
2.82 ppb
U
U
U
2.14 ppb
U
U
21.059 ppb
Southern Area
Pond
0.334 ppb
U
0.46 ppb
U
0.84 ppb
U

FACILITY LAYOUT
MISSOURI FIELD DEMONSTRATION
OF U.S. EPA
MOBILE INCINERATION SYSTEM
AT DENNEY FARM SITE

Data = 2,3,7,8-TCDD concentrations.
U = Not detected at 0.300 ppb detection limit.

Figure 32. Final Allocation of Areas With Their Levels of Dioxin Contamination.

clean soil in accordance with the cleanup criteria. The dioxin concentrations remaining after excavation are indicated in Figure 33.

Buildings and Equipment Sampling and Decontamination

Wipe sampling of the sheet metal walls, concrete foundations, and wood framework of the buildings was conducted in order to determine the level and extent of contamination in the buildings. The metal, wood, and concrete were each wipe tested separately. Coring samples of the foundations were also taken. The methods used are described below.

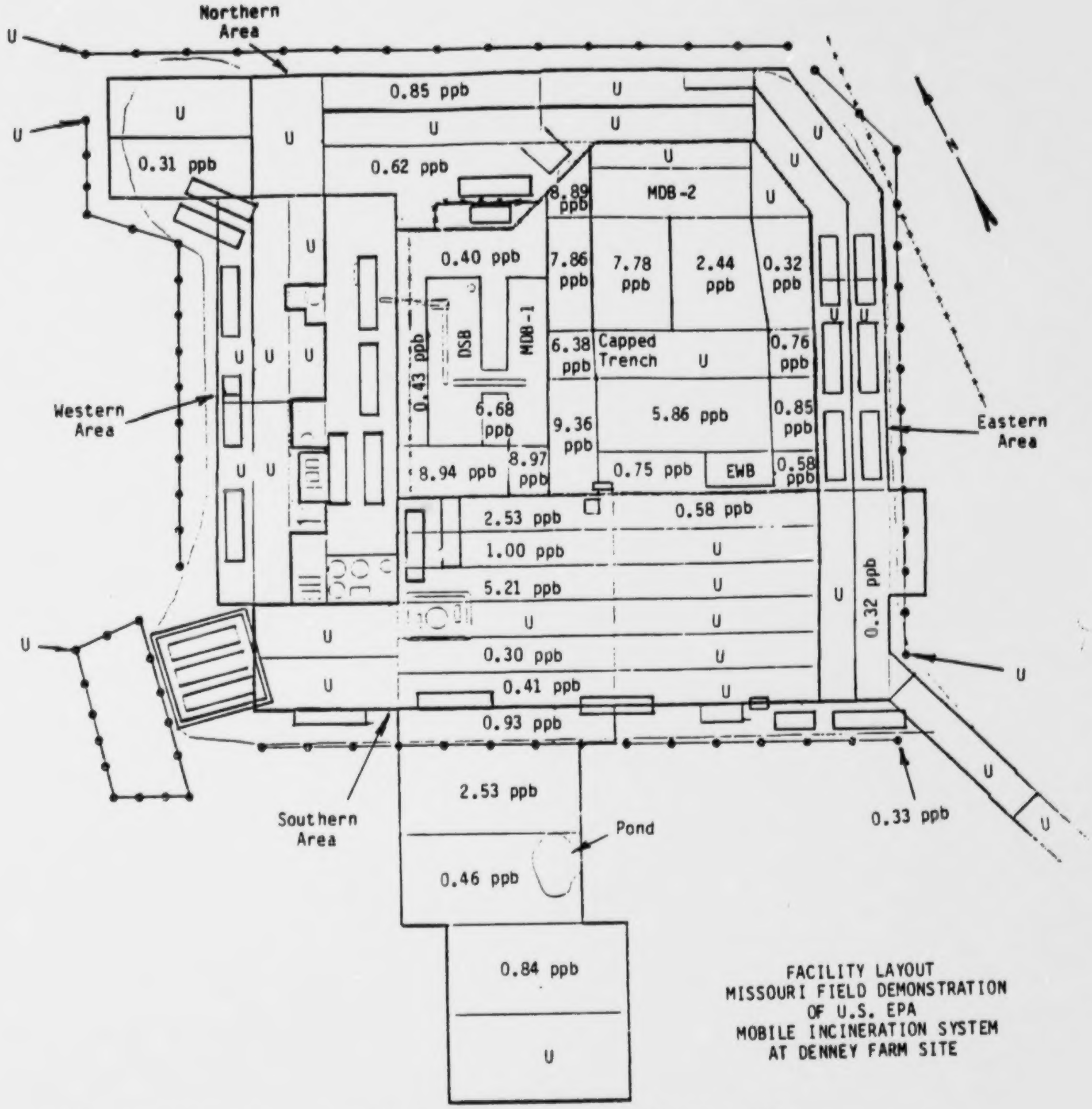
Wipe samples were taken using 3-in. by 3-in. sterile gauze pads that were soaked with isooctane. The sampling procedure consisted of wiping several areas over a designated portion of the building with the gauze so that the total area wiped was 2500 cm^2. The gauze was placed in an 8 oz jar. This procedure was used to collect samples for metals, organics/PCBs, and 2,3,7,8-TCDD analyses.

Concrete floor dust samples were collected from random locations throughout the buildings by using an impact drill with 1-in. carbide tipped bits to obtain dust from the entire depth of concrete. The dust was composited into three 8-oz jars for metals, organics/PCBs, and 2,3,7,8-TCDD analyses.

Buildings were decontaminated by scrubbing with brushes using a detergent solution and rinsing with high pressure water or steam cleaning. This was preceded by scraping when necessary. The decontamination process was repeated until sampling and analyses showed that residual contamination was below the action levels.

All building materials were decontaminated to the action levels indicated on Table 60 except for some of the wood. The contaminated wood was fed to the MIS while it was still in operation. The buildings were all disassembled and removed from the site. The foundations remained and were covered with a minimum of one foot of clean soil.

All equipment was decontaminated by scrubbing with brushes using detergent solution, and rinsing with high pressure water or steam cleaning. The process was repeated until sampling and analyses showed that the residual contamination was below the action levels. It should be noted that although the MIS closure plan [9] stipulated an equipment cleanup level of 10 pg/cm^2 for dioxin, the equipment was cleaned to meet the more stringent cleanup level of 1 pg/cm^2 indicated in the site closure plan [32].


Northern Area
U
0.85 ppb
U
U
U
0.31 ppb
U
U
0.62 ppb
U
U
U
MDB-2
U
8.89 ppb
7.86 ppb
7.78 ppb
2.44 ppb
0.32 ppb
0.40 ppb
U
DSB
MDB-1
0.43 ppb
6.38 ppb
Capped Trench
U
0.76 ppb
U U U
Western Area
6.68 ppb
9.36 ppb
5.86 ppb
0.85 ppb
Eastern Area
U U
8.94 ppb
8.97 ppb
0.75 ppb
EWB
0.58 ppb
2.53 ppb
0.58 ppb
1.00 ppb
U
5.21 ppb
U
U
0.32 ppb
U
U
U
U
0.30 ppb
U
U
0.41 ppb
U
U
0.93 ppb
U
U
2.53 ppb
Southern Area
Pond
0.33 ppb
U
0.46 ppb
0.84 ppb
U
FACILITY LAYOUT
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AT DENNEY FARM SITE

Site covered by a minimum of 1 foot of clean soil.
Data = 2,3,7,8-TCDD concentrations.
U = Not detected at 0.300 ppb detection level.

Figure 33 Dioxin Levels at Denney Farm Remaining After Excavation and Site Closure.

Wastewater generated during the decontamination process was passed through a filter train consisting of 50 micron and 20 micron paper filters, a sand filter, and two activated carbon filters. The filters were mounted in series. The filter trains were incinerated periodically. All water was discharged in accordance with the NPDES permit for the site.

Some contaminated material was generated after the incinerator was shutdown for dismantling. This material included paper filters, carbon filters, sludge from wastewater tanks, and floor sweepings. This material was put into marked and sealed drums and sent to a permitted storage facility.

DISASSEMBLY AND TRANSPORT OF INCINERATION SYSTEM

The disassembly and transport strategy for the MIS components depended upon whether the equipment was rented, trailer-mounted or mounted in other ways. Generally, the decontaminated components of the MIS were disassembled only to the degree that all elements could be mounted on over-the-road equipment and transported back to the EPA Edison, New Jersey, facility. The non-rented equipment required a total of 21 trailers for transport. The disassembly and transportation strategies are discussed below.

The rental equipment, listed above in the closure summary, was returned to the appropriate vendors after being restored to its "as supplied" condition.

Many of the major components consisting of the kiln, SCC, MX scrubber, and flue gas analyzers were mounted on seven trailers. Disassembly of the trailer-mounted units was conducted as follows: The kiln and SCC were deslagged. The equipment was cleaned and painted. The front one third of the SCC was removed and placed on another trailer to bring the SCC trailer within highway weight restrictions. All service piping and three-phase cables were disconnected, plugged, capped, and tagged. All instrumentation was protected and sealed. The trailers were inspected, serviced, and prepared for road operation.

The remaining equipment, consisting of the WEP, cyclone, CPI separator, pumps, piping, hoses, interconnecting electrical cable, storage tanks, etc., were loaded on flat bed trailers after cleaning and disassembly.

The WEP and cyclone required special handling. The electrode assemblies were removed and packed in separate crates and the WEP was filled with styrofoam packing. The support frame of the WEP was modified to allow shipment of the unit within its frame. Cross-beams to which the platforms were attached were replaced with shorter beams to bring the unit within the permissible shipping clearances. The WEP was loaded on a flat bed trailer and shipped in a horizontal position. The cyclone also was shipped completely within its support frame. Preparation of the cyclone for shipment consisted of removing the spring supports and replacing them with rigid links. Shims were then welded between the unit and its vertical guides.

The process water system and electrical system were disassembled and inspected. All steel and plastic piping was scrapped because of reduced wall thickness or internal scale buildup. Only rubber hoses and trailer-mounted piping for the process water system was salvaged. All electrical cables were coiled and placed on trailers for shipping.

All remaining equipment was disassembled, placed on pallets or crated if required and then loaded onto flat bed trailers for shipment.

LESSONS LEARNED

Several important lessons were learned from this closure experience that could make future closure operations of this nature more efficient. These lessons are discussed below.

The hot zone at Denney Farm was separated from the surrounding area by a fence, and the buildings holding the hazardous wastes were designed for spill control. However, some materials handling occurred outside the buildings creating the potential for contamination of hot zone soils. Contamination in the hot zone, which was at a higher elevation than the rest of the site, created the potential for contamination to migrate outside the hot zone during periods of heavy rainfall. In fact, the spread of contamination outside the hot zone boundary was discovered during closure. A narrow plume of contaminants migrated out of the hot zone and was carried along by stormwater runoff into the adjacent wooded area. The discovery of this plume necessitated additional sampling and analysis work during closure to define the area of contamination, as well as additional remediation work to correct the condition.

Contamination outside of the buildings can be minimized by confining feed handling to inside the buildings. The use of conveyors to transport the contaminated soil between buildings did reduce handling outside the buildings after they were installed in March, 1988. A dike at the fence line would have been effective in minimizing the spread of contamination from the hot zone to the outside.

Conducting routine soil sampling in both the hot zone and safe zone during the operational phase of the field demonstration would have been useful to minimize contamination of the site. Having such a program in place would have allowed earlier discovery of the soil contamination. This in turn would have allowed site personnel to remediate the situation and prevent the spread of contamination beyond the hot zone.

It would have been useful to have had routine wipe testing of the equipment and buildings during the operational phase of the MIS program. If this had been done, potential sources of contamination around the MIS and in the personnel decontamination area could have been identified and remediated quickly, and additional contamination of these areas could have been prevented. This in turn would have helped simplify final closure operations.

FUTURE OF THE MOBILE INCINERATION SYSTEM

Although the MIS is temporarily being stored at the EPA Facility in Edison, New Jersey, plans for its future were made at the beginning of 1989, when EPA decided to make the unit available to private developers or other federal agencies through the Federal Technology Transfer Act (FTTA) [32]. This law allows EPA to seek a technology partnership with a commercial or other governmental organization for further development of the system.

A Technology Transfer Program for the MIS was held in Monett, Missouri on March 29, 1989. The presentation consisted of two identical half-day sessions. The first part of each session presented the FTTA legislation, and technical and permitting information on the MIS. The second part of each session involved a tour of the MIS operation at the Denney Farm site. There were 42 attendees representing 31 companies at the program. Interested parties were requested to submit proposals to EPA stating how they would further develop the technology and provide financial support for this development. Several proposals were received and are currently being reviewed by EPA so that a technology partner can be selected. Anyone interested in more information on the future of the MIS should contact the Releases Control Branch of the Risk Reduction Engineering Laboratory at (201) 321-6635.

SECTION 10

PROCESSING ECONOMICS

Since the MIS was a development unit, the original processing costs were high, amounting to $2800 per ton. This high cost was caused by a number of factors but was chiefly related to processing rate, reliability and manpower requirements. As the MIS was operated, parameters affecting these factors were identified and cost reductions were achieved by addressing mainly the first two factors as described below.

COST IMPROVEMENTS

Due to both the capacity increases and the reliability improvements, the costs have been reduced about 60% to $1100 per ton. Unit costs of processing the waste materials for each campaign have been calculated and are presented in Table 63. The costs for the original soil incineration activities was $2800 per ton. The soils incineration activities conducted later during the Verona and Closure activities cost from $1100 to $1340 per ton. The original materials incinerated, the Verona materials, and the Closure materials all consisted primarily of soils. The feed rate for the Verona and Closure materials was on the order of 3000 lb/hr to 4000 lb/hr, which doubled the original 2000 lb/hr maximum feed rate.

Since processing rates are dependent on the feed characteristics, the costs varied widely for high calorific value feeds which had to be processed at reduced rates. High calorific value feeds were trash and brominated sludge. For instance, the reduced processing costs were not achieved for the 1987 and Baldwin Park activities because the feed materials contained large quantities of trash. The trash included plastics, glass, insulation materials, wood, etc. and was fed concurrently with the soils. When feeding the large amounts of trash, an average feed rate of approximately 900 lb/hr was achieved. The system also experienced more downtime due to slagging and feed system jams. The 4000 lb/hr rate is not possible with the trash due to its high heat content. The high calorific value of the Syntex sludge created a feed limit of 2000 lb/hr for that material as well.

Future Cost Improvements

Further cost improvements can be obtained by reducing manpower requirements. This can be achieved by centralizing the control and air monitoring systems and by automating the ash removal system. These improvements should reduce operating costs by about $400 per ton. The projected $700 per ton cost, compares favorably with commercial rates of over $400 per ton considering scaling factors of these greater than 6 ton per hr units.

TABLE 63 INCINERATION COSTS

Material	Dates processed	Amount processed (lbs)	Cost per ton ($)
Soil	10/85-2/86	2,100,000	2800
Soil and trash	6/87-9/87	1,300,000	2530
Baldwin Park (soil and trash)	2/88-4/88	1,125,000	3140
Verona (soil)	5/88-8/88	3,100,000	1340
Syntex (sludge)	9/88-1/89	2,163,000	2820
Closure (soil)	1/89-4/89	2,540,000	1100

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APPENDIX A

OXYGEN ENRICHMENT CORRECTION FOR PARTICULATE EMISSIONS PER OPERATING PERMIT

SAMPLE CALCULATIONS

Sample calculations use data collected during Test 3.

PARTICULATE EMISSION RATE

I. EPA Method 5

$$P_m = \frac{DRY_{M5}}{GAS_{DSCM}}$$

Where: DRY_{M5} = Method 5 filter weight gain plus the residue from the acetone wash. (Table 8) - 189.06 mg

GAS_{DSCM} = Gas sampled during the particulate test from stack sampling results. (Table 8) - 42.903 dscf

$$P_m = \frac{(189.06 \text{ mg filter} + \text{mg wash})}{(42.903 \times 0.02832 \text{ m}^3)}$$

$$P_m = 155.6 \text{ mg/m}^3$$

PARTICULATE CORRECTION FACTORS

I. Facility Permit[1] - enriched oxygen correction factor.

$$P_c = P_m \times \frac{(O_3 - O_1)}{(O_3 - y)} \times \frac{N}{79}$$

Nomenclature as defined below:

1.1 Data required for Calculation

A_1 = Kiln combustion air flowrate from FI-102 = 1036 scm/hr
A_2 = SCC combustion air flowrate from FI-203 = 2000 scm/hr
P = Kiln pure oxygen flowrate from FIC-155 = 200 scm/hr
P_m = Measured stack particulate concentration from stack sampling vendor
Y = Measured stack oxygen concentration from stack sampling vendor (Orsat) = 9.4%

1.2 Calculation Basis of Particulate Correction Factor

$$P_c = P_m \times \frac{(O_3 - O_1)}{(O_3 - y)} \times \frac{N}{(79)}$$

Where:

P_c = corrected concentration of particulate matter.

P_m = measured concentration of particulate matter.

O_3 = percent of oxygen in oxygen enriched combustion air (theoretical).

O_1 = percent of oxygen in stack gas at 50% excess oxygen enriched combustion air (theoretical).

y = measured oxygen in stack gas (Orsat).

N = percent of nitrogen in oxygen enriched combustion air (theoretical).

1.3 Particulate Correction Calculation

a) Calculation of enriched oxygen concentration.

$$O_3 = \frac{P + 0.21\ (A_1 + A_2)}{P + A_1 + A_2} \times 100$$

$$= \frac{200 + 0.21\ (1036 + 2000) \times 100}{200 + 1036 + 2000} = \underline{25.9}\%$$

$$N = (100 - O_3)\%$$

$$= 100 - 25.9 = \underline{74.1}\%$$

b) Calculation of theoretical oxygen in stack gas assuming 50% excess oxygen.

$$O_1 = \frac{1}{3}\ (O_3) = \frac{1}{3} \times 25.9 = \underline{8.6\%}$$

c) Calculation of corrected particulate emissions.

$$P_c = P_m \times \frac{(O_3 - O_1)}{(O_3 - Y)} \times \frac{(N)}{(79)}$$

$$= \frac{0.0679\ \text{gr}}{\text{dscf}} \times \frac{(25.9 - 8.6)\%}{(25.9 - 9.4)\%} \times \frac{74.1\%}{79\%}$$

$$= 0.0062\ \text{gr/dscf}$$

APPENDIX B

RISK ANALYSIS

RISK ASSESSMENT FOR MINOR RELEASE OF FURANS FROM THE EPA MOBILE INCINERATION SYSTEM

October 7, 1987

SUMMARY

This risk assessment addresses the excess cancer risk that is associated with a release of furans from the stack of the EPA Mobile Incineration System (MIS) due to an equipment malfunction which occurred on August 1, 1987. The malfunction occurred in bearings on the kiln, which caused an emergency shutdown of the unit. This resulted in production of furans from the PCBs that were in the kiln at that time. The furans contaminated the process water which, in turn, provided a source of contamination from stack emissions. It should be emphasized that this was the first release of any contaminants from the EPA mobile incinerator during the past 3 years operation at the Denney Farm.

A risk analysis was conducted using state-of-the-art methodology and in accordance with the US EPA procedures. The results show that this incident was minor. There was no additional risk to the public resulting from this incident. To put this matter into perspective, it would take more than 16,000 additional similar incidents to increase the theoretical cancer risk of the entire surrounding populace by one. In addition, the data used was conservative; using a "worst case scenario".

EXTENT OF THE RELEASE

It is well known that furans are significantly less toxic than dioxins. It should be emphasized that no significant amount of dioxins were relased in this incident. The EPA risk assessment guidelines (1) suggest that the amount of furans released be translated in terms of "equivalent 2,3,7,8-tetrachlorodibenzo-(p)-dioxin (TCDD)".

The incident resulted in a maximum hourly release of 6.15 mg/hr "equivalent TCDD" for approximately 100 hours as shown in the incident history given in Table 1. Stack emissions would be expected to occur only during those periods when the Induced Draft (ID) fan was operating. The stack emissions were measured by Alliance Technologies Corporation as part of the stack sampling for a trial burn test performed on the day after the process water contamination. The process water sample taken before this trial burn test began on 8/2/87, showed the presence of the same furans as were detected in the stack emission during the trial burn test. Based on the data from the previous successful PCB trial burn in 1983, the dioxin trial burn in 1985, test 2 and 3 of the 1987 trial burn, and the operating conditions of the incinerator during test 5 being similar to previously successful tests, it can be concluded that no measurable dioxins or furans resulted from test 5 and that the stack contamination arose solely as a result of the contaminated process water.

The calculations of the amount of "equivalent TCDD" from the measured furans were done according to the EPA guidelines and are given in Table 2. For the purposes of this analysis, the initial hourly release of 6.15 mg/hr is conservatively assumed constant for the total operating period of 100 hours.

The reason that this emission level is judged to be conservative is that the furans have been shown by water analysis data to be associated predominantly with solids, and those solids were, during the period in question, continuously being removed from the water by an inclined plate separate and filter system. Therefore, a more realistic estimation of the emission level over the period would involve a steady decline over time as the fine particulates are removed. However, for the purposes of this risk assessment, a more conservative approach was chosen.

Approach in Exposure Assessment

The analysis was completed based upon the October 1984 risk assessment prepared for the TCDD-contaminated-soil trial burn (2). The approach in this analysis was to model the exposure to TCDD from the stack emissions. EPA's Industrial source Complex Short Term (ISCST) (3) air dispersion computer model (version 6) was employed to calculate ground level TCDD concentrations in a 50 km radius using actual wind speeds and direction as recorded at the Springfield, Mo. airport.

This report focuses on the risk from "equivalent TCDD" emission only (even though only furans were released). In addition, because of the short duration of the incident only the inhalation route is analyzed. Exposure due to ingestion of soil particles is not included assuming no particulate buildup in the soil.

The ISCST model results were combined with the population distribution given in reference 2 (see Tables 3 and 4). With this, the number of individuals theoretically exposed can be estimated and an upper bound estimate of the number of possible cancer cases are calculated.

It should be noted that for some sector segments (areas bounded by ring distances from stack and adjacent compass directions) the population is shown as zero. This in fact may not always be true, but is due to limitations in retrieving population density on such small scale and numbers.

The input parameters assumed for the model are listed in Table 5. The dispersion of the stack plume depends upon the atmospheric turbulence caused by both the wind and by surface heating and cooling effects. Stability categories have been established and are designated by the letters A thru F representing the most unstable to the most stable atmospheric conditions. Actual stability classes for this time period were not available. Therefore, initial screening computer runs were completed with various wind speeds and stabilities. The dispersion model predicted the highest contaminant concentrations with D stability for areas located close to the site. In addition, the model predicted the highest contaminant concentrations with F stability for the more populated areas located farther from the site. Detailed modeling computer runs were then performed separately using both the D and F stabilities as the most conservative conditions.

Risk Calculations

The approach used in calculating the lifetime upper bound estimate of excess cancer risk is:

$$\text{Upper Bound Estimate of Cancer Risk} = 1 - e^{-}\,(\text{cancer potency factor x exposure})$$

The cancer potency factor (or 95% upper-limit of the linear slope factor) for TCDD is 0.156 kg day/ng. The derivation of this factor is described in EPA's Ambient Water Quality Criteria Document for: 2,3,7,8-TCDD (4).

The estimation of human exposure by inhalation to TCDD was obtained by using the hourly averaged concentration values generated by the model for each sector segment. The model assumes that the emissions are continuous at a steady state for the entire period of the incident. This value was then multiplied by the breathing rate for an individual (22 m^3/day) to give the amount of TCDD inhaled per day. It was assumed that everything inhaled was retained. Lifetime upper bound estimates of risk for this exposure was then calculated as follows:

$$\text{Upper bound Estimate of Risk} = 1 - e^{-}\ \underset{\text{Factor}}{\text{Cancer Potency}} \times \frac{\text{Conc. x Respiration x Duration}}{\text{body wt. x 70 yr lifetime}}$$

Note: For low exposure values:

$$\begin{aligned}\text{Upper bound Estimate of Risk} &= 1 - e^{-}\,(\text{cancer potency factor x exposure})\\ &= \text{cancer potency factor x exposure}\end{aligned}$$

$$\text{for (cancer potency factor x exposure)} < 10^{-3}$$

Therefore, the upper bound estimates of risk was calculated as:

$$\text{Upper bound Estimate of Risk} = 0.156\ \frac{\text{kg day}}{\text{ng}}\quad \frac{\text{conc. x 22 } m_3\text{/day x 4.2 days}}{\text{70 kg x } \frac{\text{365 day}}{\text{yr}} \text{ x 70 yrs/lifetime}}$$

Discussion of Results

Tables 3 and 4 list the ground level concentrations of "equivalent TCDD" (from furans) in micrograms/m^3 assuming that the incinerator is operating at steady state. These values are then used in calculating an upper bound estimate of excess cancer risk for each sector segment.

Tables 3 and 4 also list the upper bound estimates of the number of possible cancer cases per sector segment as computed using the risk values and population values. The maximum risk value for any segment was 8.24×10^{-8} for D and 2.27×10^{-8} for F stabilities. As previously mentioned, the sector segments for which population is indicated as zero may not always be so. This is due to the limitations in retrieving population information from census data for small areas and very low population densities.

Summing all the values contained in these tables gives an upper bound estimate of the cumulative number of cancer cases for each stability. This value is 2.27×10^{-5} and 6.03×10^{-5} cancer cases for D and F stabilities, respectively. Since these are very small fractions, a single case of cancer would not be attributed to the incident. The results incorporate the following conservative assumptions:

- All furans released were assumed to be 2,3,7,8-substituted regardless of the overall degree of chlorination and, therefore, are potentially the most toxic in each set of isomers. The risks due to non-2,3,7,8 substituted furans would be two orders of magnitude lower.
- Emission rates constant at the initial values.
- Total retention and adsorption of inhaled TCDD.

Risk assessment experts at EPA have reviewed these results and they believe that the emissions during this incident have not posed any significant risk to the surrounding populations. Considering the risk values and the population exposed, the expected number of cancer cases is very low when compared to other situations for which the Agency has expressed a public health concern.

In any event, steps have been taken at the MIS site to prevent the recurrence of such an incident in the future. Specifically, this incident occurred during a trial burn involving the incineration of PCBs on solids at a high concentration. This was done to determine the performance of the incinerator under extreme conditions. In reality, the probability of feeding similar levels of PCBs to the MIS again is extremely remote. Furan contaminants would not necessarily be formed from all potential feeds to the incinerator under similar conditions to those that occurred with the PCBs.

Further, had the secondary combustion chamber burners and other downstream equipment remained on after the kiln burners had been shut off, the furans generated in the kiln would have been subjected to the high temperatures of the secondary chamber and the emission would not have occurred. The incinerator operators have been instructed, and the operator's manual and contingency plan will be modified such that, should a similar kiln stoppage occur in the future, the operators will ensure that the secondary chamber burners are kept on.

REFERENCES

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2. US Environmental Protection Agency, October 1984. Risk Assessment for the Trial Burn of TCDD-contaminated Soil at Denney Farms, Missouri. Office of Health and Environmental Assessment, Washington, DC. EPA/600/x-84/255.

3. US Environmental Protection Agency, June 1986. Industrial Source Complex (ISC) Dispersion Model Users Guide, 2nd Edition. Office of Air Quality Planning and Standards, Research Triangle Park, NC EPA/450/4-86/005a.

4. US Environmental Protection Agency, 1984. Ambient Water Quality Document for 2,3,7,8-TCDD. Environmental Criteria and Assessment Office, Cincinnati, OH. EPA/444/5-84/007.

TABLE 1. INCIDENT HISTORY

Date	Time	Description
8/01/87	0045-0315 (2.5 hrs)	Kiln & SCC burners are off due to thrust bearing failure. Water contaminated during 15-30 minutes after this incident. Fans are on. Quench and WEP systems are on.
8/01/87	0315-1030 (7.25 hrs)	Kiln & SCC burners are off for repairs. Fans are off.
8/01/87	1030-2230 (12 hrs)	Systems turned on to prepare for the trial burn. Fans are on. No material being fed to the system. Quench and WEP systems are on.
8/01/87- 8/02/87	2230-0900 (10.5 hrs)	Kiln & SCC are started. Trial burn test 5 takes place. Stack emissions data taken for 3.5 hrs during this period.
8/02-87	0900-1430 (5.5 hrs)	Kiln & SCC burners are off. Maintenance to repair quench distribution manifold. Fans are off.
8/02/87	1430-1515 (0.75 hrs)	Kiln & SCC are started. Fans are on
8/02/87	1515-2315 (8.0 hrs)	Kiln & SCC burners are off. Fans are off. Quench manifold repaired.
8/02/87- 8/06/87	2315-0400 (76.76 hrs)	Restart kiln. Operations on Denney Farm materials at approximately 25% of capacity (1000 lb/hr). Fans are on. Quench and WEP systems are on.
8/02/87	2300	Water contamination first discovered.
8/06/87	0400	System shutdown for decontamination. Fans turned off.
8/18/87	0900	Stack emission results from 8/1 trial burn test available. First indication of furans released in stack emission.

TABLE 2. PRELIMINARY RESULTS OF ANALYSIS FOR DIOXINS AND FURANS COLLECTED IN MM5 TRAIN

	Relative toxicity(a)	Measured emission (ug)	TCDD Equivalent (ug)
TCDD	1.0	< 0.011	< 0.011
TCDF	0.1	17.0	1.7
PeCDD	0.5	< 0.014	< 0.007
PeCDF	0.1	25.0	2.5
HxCDD	0.04	0.02	0.0008
HxCDF	0.01	4.8	0.048
HpCDD	0.001	< 2.7	0.00
HpCDF	0.001	0.330	0.00033
OCDD	0.00	0.0074	0.00
OCDF	0.00	0.011	0.00
		TOTAL EQUIVALENT TCDD	4.267

(a) Assumes all compounds 2,3,7,8 substituted. Relative Toxicity Factors based upon EPA current recommended values contained in "Interim Procedures for Estimating Risks Associated with Exposures to Mixtures of Chlorinated Dibenzo-p-dioxins and -Dibenzofurans (CDDs and CDFs)", EPA 625/3-87/012, March 1877.

Estimated emissions = 4.267 ug x 2455 dscf/m / 102.2 dscf
= 102.5 ug/min - 6.15 mg/hr

Table 3

```
TRIAL BURN CONTAMINATION INCIDENT RISK ANALYSIS
POLLUTANT : TCDD                         SOURCE : DEWEY FARM, MD.                 EMISSION TYPE : STACK
REPORTED TABULAR VALUES WITHIN INDIVIDUAL SECTOR SEGMENTS :                        HOURLY AVERAGED CONCENTRATION (UG/M3)
STABILITY : D                                                                      POPULATION (PEOPLE)
                                                                                   UPPER BOUND OF RISK/PERSON
                                                                                   TOTAL RISK/SECTOR SEGMENT (UPPER BOUND X POPULATION)

DISTANCES  (KM)    0.0 - 0.5  0.5 - 1.0  1.0 - 2.0  2.0 - 3.0  3.0 - 4.0  4.0 - 5.0  5.0 - 10.0 10.0-15.0  15.0-25.0  25.0-50.0
                                                                                                                      SECTOR     MAX. UPPER
                                                                                                                      RISK       BOUND RISK
SECTOR  MID-ANGLE
   N        0.0    1.025E-05  8.645E-06  3.810E-06  1.437E-06  7.864E-07  5.146E-07  3.696E-07  1.317E-07  7.312E-08  3.492E-08
                           0          0          0          0          0          0          0       1491        418       6796
                   8.239E-08  6.950E-08  3.070E-08  1.156E-08  6.323E-09  4.137E-09  2.972E-09  1.059E-09  5.879E-10  2.808E-10             8.239E-08
                   0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  1.579E-06  2.457E-07  1.908E-06  3.732E-06
  NNE      22.5    5.719E-06  4.784E-06  2.002E-06  6.979E-07  3.640E-07  2.299E-07  1.607E-07  5.258E-08  2.780E-08  1.250E-08
                           0          0          0          0          0        344          0       3258       2212       2663
                   4.598E-08  3.846E-08  1.609E-08  5.611E-09  2.926E-09  1.849E-09  1.292E-09  4.228E-10  2.235E-10  1.005E-10             4.598E-08
                   0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  6.360E-07  0.000E+00  1.377E-06  4.943E-07  2.675E-07  2.775E-06
   NE      45.0    3.107E-06  2.695E-06  1.178E-06  4.106E-07  2.112E-07  1.312E-07  9.013E-08  2.720E-08  1.340E-08  5.355E-09
                   0.000E+00  0.000E+00          0          0          0          0          0       1559       3898      12487
                   2.498E-08  2.167E-08  9.467E-09  3.302E-09  1.698E-09  1.055E-09  7.247E-10  2.187E-10  1.077E-10  4.306E-11             2.498E-08
                   0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  3.409E-07  4.198E-07  5.376E-07  1.298E-06
  ENE      67.5    4.498E-07  3.172E-07  1.078E-07  3.142E-08  1.464E-08  8.466E-09  5.508E-09  1.377E-09  5.950E-10  2.040E-10
                           0          0          0          0          0          0        504          0       1799       3062
                   3.617E-09  2.551E-09  8.666E-10  2.526E-10  1.177E-10  6.807E-11  4.429E-11  1.107E-11  4.784E-12  1.640E-12             3.617E-09
                   0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  2.232E-08  0.000E+00  8.606E-09  8.303E-09  3.923E-08
   E       90.0    1.948E-06  1.559E-06  6.195E-07  2.164E-07  1.144E-07  7.332E-08  5.194E-08  1.790E-08  9.809E-09  4.641E-09
                           0          0          0          0          0          0          0        646       1002       4522
                   1.567E-08  1.254E-08  4.981E-09  1.740E-09  9.198E-10  5.895E-10  4.176E-10  1.439E-10  7.887E-11  3.732E-11             1.567E-08
                   0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  9.298E-08  7.903E-08  1.687E-07  3.407E-07
  ESE     112.5    2.734E-08  2.232E-08  7.072E-09  1.496E-09  5.440E-10  2.550E-10  1.360E-10  1.700E-11  0.000E+00  0.000E+00
                           0          0          0          0          0          0          0          0        183       2874
                   2.198E-10  1.795E-10  5.686E-11  1.203E-11  4.374E-12  2.050E-12  1.093E-12  1.367E-13  0.000E+00  0.000E+00             2.198E-10
                   0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
   SE     135.0    1.377E-06  1.377E-06  7.630E-07  2.882E-07  1.517E-07  9.525E-08  6.582E-08  2.008E-08  9.928E-09  3.978E-09
                           0          0          0          0          0          0          0        344          0       5863
                   1.107E-08  1.107E-08  6.135E-09  2.317E-09  1.220E-09  7.658E-10  5.292E-10  1.614E-10  7.982E-11  3.198E-11             1.107E-08
                   0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  5.553E-08  0.000E+00  1.875E-07  2.431E-07
  SSE     157.5    5.291E-06  4.813E-06  2.263E-06  8.179E-07  4.289E-07  2.705E-07  1.883E-07  5.992E-08  3.086E-08  1.320E-08
                           0          0          0          0          0        278          0          0        741       2214
                   4.254E-08  3.870E-08  1.820E-08  6.576E-09  3.448E-09  2.175E-09  1.514E-09  4.818E-10  2.481E-10  1.068E-10             4.254E-08
                   0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  6.046E-07  0.000E+00  0.000E+00  1.838E-07  2.363E-07  1.025E-06
   S      180.0    8.320E-06  8.264E-06  4.434E-06  1.761E-06  9.773E-07  6.431E-07  4.633E-07  1.658E-07  9.217E-08  4.406E-08
                           0          0          0          0          0          0        625          0          0       2773
                   6.689E-08  6.644E-08  3.565E-08  1.416E-08  7.858E-09  5.170E-09  3.725E-09  1.333E-09  7.411E-10  3.543E-10             6.689E-08
                   0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  2.328E-06  0.000E+00  0.000E+00  9.824E-07  3.311E-06
```

Table 3 (cont'd.)

```
SSW   202.5  3.148E-06 7.977E-06 4.261E-06 1.669E-06 9.142E-07 5.945E-07 4.240E-07 1.462E-07 7.982E-08 3.653E-08
                     0         0         0         0         0         0         0       234      4509      5289
             6.551E-08 6.414E-08 3.426E-08 1.342E-08 7.351E-09 4.780E-09 3.409E-09 1.176E-09 6.370E-10 2.937E-10           6.551E-08
             0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.751E-07 2.878E-06 1.554E-06 4.701E-06
 SW   225.0  8.277E-06 7.219E-06 3.213E-06 1.131E-06 5.633E-07 3.628E-07 2.495E-08 7.536E-08 3.715E-08 1.484E-08
                     0         0         0         0         0         0         0         0       360      1933
             6.655E-08 5.804E-08 2.583E-08 9.091E-09 4.690E-09 2.917E-09 2.006E-10 6.059E-10 2.987E-10 1.193E-10           6.655E-08
             0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.075E-07 2.307E-07 3.382E-07
WSW   247.5  6.519E-06 5.752E-06 2.671E-06 9.096E-07 5.291E-07 3.387E-07 2.386E-07 7.898E-08 4.162E-08 1.841E-08
                     0         0         0         0         0         0         0      1590      1218      2869
             5.242E-08 4.625E-08 2.148E-08 7.957E-09 4.254E-09 2.724E-09 1.919E-09 6.350E-10 3.346E-10 1.480E-10           5.242E-08
             0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.010E-06 4.075E-07 4.247E-07 1.842E-06
  W   270.0  2.430E-06 1.926E-06 7.503E-07 2.576E-07 1.349E-07 8.599E-08 6.066E-08 2.071E-08 1.131E-08 5.321E-09
                     0         0         0         0         0         0         0         0       856     11662
             1.954E-08 1.549E-08 6.033E-09 2.071E-09 1.085E-09 6.914E-10 4.877E-10 1.665E-10 9.090E-11 4.278E-11           1.954E-08
             0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 7.781E-08 4.989E-07 5.767E-07
WNW   292.5  1.523E-06 1.484E-06 7.810E-07 3.073E-07 1.695E-07 1.109E-07 7.953E-08 2.788E-08 1.525E-08 7.106E-09
                     0         0         0         0         0         0       670      3339      1391      3933
             1.224E-08 1.194E-08 6.280E-09 2.471E-09 1.363E-09 8.919E-10 6.394E-10 2.242E-10 1.226E-10 5.713E-11           1.224E-08
             0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 4.284E-07 7.485E-07 1.705E-07 2.247E-07 1.572E-06
 NW   315.0  2.229E-06 1.923E-06 8.430E-07 2.951E-07 1.520E-07 9.449E-08 6.492E-08 1.960E-08 9.656E-09 3.859E-09
                     0         0         0         0         0         0         0      3452      2895      4607
             1.792E-08 1.546E-08 6.778E-09 2.373E-09 1.222E-09 7.597E-10 5.220E-10 1.576E-10 7.764E-11 3.103E-11           1.792E-08
             0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 5.440E-07 1.774E-07 1.429E-07 8.644E-07
NNW   337.5  1.210E-06 9.943E-07 4.175E-07 1.516E-07 8.109E-08 5.212E-08 3.607E-08 1.241E-08 6.613E-09 2.958E-09
                     0         0         0         0         0         0         0         0       458      1181
             9.725E-09 7.995E-09 3.356E-09 1.219E-09 6.520E-10 4.191E-10 2.965E-10 9.978E-11 5.317E-11 2.378E-11           9.725E-09
             0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.435E-08 2.809E-08 5.244E-08
                                                                         PREDICTED CANCER CASES -- 2.271E-05 8.229E-08
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Table 4

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TRIAL BURN CONTAMINATION INCIDENT RISK ANALYSIS
POLLUTANT : TCDD                  SOURCE : DENNEY FARM, MO.                EMISSION TYPE : STACK
REPORTED TABULAR VALUES WITHIN INDIVIDUAL SECTOR SEGMENTS :                HOURLY AVERAGED CONCENTRATION (UG/M3)
STABILITY : F                                                              POPULATION (PEOPLE)
                                                                           UPPER BOUND OF RISK/PERSON
                                                                           TOTAL RISK/SECTOR SEGMENT (UPPER BOUND X POPULATION)

DISTANCES  (KM)   0.0 - 0.5 0.5 - 1.0 1.0 - 2.0 2.0 - 3.0 3.0 - 4.0 4.0 - 5.0 5.0 - 10.0 10.0-15.0 15.0-25.0 25.0-50.0
                                                                                                             SECTOR     MAX. UPPER
                                                                                                             RISK       BOUND RISK
SECTOR  MID-ANGLE
  N         0.0   5.625E-07 2.491E-06 2.823E-06 2.617E-06 1.987E-06 1.537E-06 1.213E-06 5.752E-07 3.620E-07 2.035E-07
                          0         0         0         0         0         0         0      1491       418      6796
                  4.523E-09 2.003E-08 2.270E-08 2.104E-08 1.598E-08 1.235E-08 9.912E-09 4.657E-09 2.910E-09 1.636E-09            2.270E-08
                  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 6.943E-06 1.217E-06 1.112E-05 1.929E-05
 NNE       22.5   1.520E-07 6.346E-07 6.912E-07 6.212E-07 4.497E-07 3.349E-07 2.604E-07 1.093E-07 6.319E-08 3.164E-08
                          0         0         0         0         0       344         0      3258      2212      2663
                  1.224E-09 5.102E-09 5.558E-09 4.995E-09 3.616E-09 2.692E-09 2.094E-09 8.790E-10 5.081E-10 2.544E-10            5.558E-09
                  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 9.262E-07 0.000E+00 2.864E-06 1.124E-06 6.774E-07 5.591E-06
  NE       45.0   1.975E-08 5.959E-08 6.023E-08 4.306E-08 2.463E-08 1.516E-08 1.005E-08 2.363E-09 6.290E-10 2.550E-10
                  0.000E+00 0.000E+00         0         0         0         0         0      1539      3898     12487
                  1.588E-10 4.791E-10 4.843E-10 3.462E-10 1.981E-10 1.219E-10 8.078E-11 1.900E-11 5.057E-12 2.050E-12            4.843E-10
                  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.962E-08 1.971E-08 2.560E-08 7.494E-08
 ENE       67.5   3.400E-10 6.120E-10 5.780E-10 2.210E-10 8.500E-11 5.100E-11 1.700E-11 0.000E+00 0.000E+00 0.000E+00
                          0         0         0         0         0         0       504         0      1799      5062
                  2.734E-12 4.921E-12 4.647E-12 1.777E-12 6.834E-13 4.101E-13 1.367E-13 0.000E+00 0.000E+00 0.000E+00            4.921E-12
                  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 6.889E-11 0.000E+00 0.000E+00 0.000E+00 6.889E-11
  E        90.0   8.653E-08 3.730E-07 4.076E-07 3.708E-07 2.754E-07 2.107E-07 1.678E-07 7.769E-08 4.830E-08 2.705E-08
                          0         0         0         0         0         0         0       646      1002      4522
                  6.957E-10 2.999E-09 3.278E-09 2.981E-09 2.214E-09 1.694E-09 1.349E-09 6.247E-10 3.883E-10 2.175E-10            3.278E-09
                  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 4.035E-07 3.891E-07 9.834E-07 1.776E-06
 ESE      112.5   0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
                          0         0         0         0         0         0         0         0       183      2874
                  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00            0.000E+00
                  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  SE      135.0   9.129E-09 3.196E-08 3.337E-08 2.647E-08 1.605E-08 1.017E-08 6.851E-09 1.666E-09 6.460E-10 1.870E-10
                          0         0         0         0         0         0         0       344         0      5863
                  7.340E-11 2.570E-10 2.683E-10 2.128E-10 1.290E-10 8.174E-11 5.508E-11 1.340E-11 5.194E-12 1.504E-12            2.683E-10
                  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 4.608E-09 0.000E+00 8.815E-09 1.342E-08
 SSE      157.5   8.084E-08 3.567E-07 3.938E-07 3.564E-07 2.517E-07 1.817E-07 1.373E-07 5.115E-08 2.700E-08 1.176E-08
                          0         0         0         0         0       278         0         0       741      2214
                  6.499E-10 2.868E-09 3.167E-09 2.866E-09 2.024E-09 1.461E-09 1.104E-09 4.113E-10 2.171E-10 9.459E-11            3.167E-09
                  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 4.062E-07 0.000E+00 0.000E+00 1.608E-07 2.094E-07 7.765E-07
  S       180.0   3.467E-07 2.492E-06 2.736E-06 2.691E-06 2.188E-06 1.744E-06 1.427E-06 6.969E-07 4.415E-07 2.506E-07
                          0         0         0         0         0         0       625         0         0      2773
                  2.788E-09 2.004E-08 2.200E-08 2.164E-08 1.759E-08 1.402E-08 1.147E-08 5.603E-09 3.550E-09 2.015E-09            2.200E-08
                  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 7.169E-06 0.000E+00 0.000E+00 5.588E-06 1.276E-05
 SSW      202.5   2.385E-07 1.270E-06 1.578E-06 1.530E-06 1.188E-06 9.134E-07 7.249E-07 3.175E-07 1.863E-07 9.433E-08
                          0         0         0         0         0         0         0       234      4509      5289
                  1.918E-09 1.021E-08 1.269E-08 1.230E-08 9.550E-09 7.344E-09 5.829E-09 2.554E-09 1.498E-09 7.585E-10            1.269E-08
                  0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 5.976E-07 6.755E-06 4.012E-06 1.136E-05
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Table 4 (cont'd.)

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SW      225.0  5.438E-08  1.667E-07  1.667E-07  1.181E-07  6.771E-08  4.175E-08  2.769E-08  6.528E-09  2.499E-09  6.800E-10
                       0          0          0          0          0          0          0          0        360       1933
               4.373E-10  1.341E-09  1.341E-09  9.493E-10  5.444E-10  3.357E-10  2.227E-10  5.249E-11  2.009E-11  5.467E-12             1.341E-09
               0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  7.233E-09  1.057E-08  1.780E-08
WSW     247.5  1.320E-07  5.569E-07  6.098E-07  5.456E-07  3.841E-07  2.771E-07  2.092E-07  7.791E-08  4.112E-08  1.792E-08
                       0          0          0          0          0          0          0       1590       1218       2869
               1.061E-09  4.478E-09  4.903E-09  4.386E-09  3.089E-09  2.228E-09  1.682E-09  6.264E-10  3.306E-10  1.441E-10             4.903E-09
               0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  9.960E-07  4.027E-07  4.113E-07  1.812E-06
W       270.0  9.474E-08  2.552E-07  4.601E-07  4.192E-07  3.126E-07  2.395E-07  1.911E-07  8.866E-08  5.515E-08  3.091E-08
                       0          0          0          0          0          0          0          0        856      11662
               7.617E-10  2.052E-09  3.699E-09  3.370E-09  2.513E-09  1.926E-09  1.536E-09  7.128E-10  4.434E-10  2.485E-10             3.699E-09
               0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  3.796E-07  2.898E-06  3.277E-06
WNW     292.5  4.636E-08  2.552E-07  3.182E-07  3.081E-07  2.385E-07  1.830E-07  1.450E-07  6.327E-08  3.706E-08  1.875E-08
                       0          0          0          0          0          0        670       3339       1391       3933
               3.744E-10  2.052E-09  2.558E-09  2.477E-09  1.917E-09  1.471E-09  1.166E-09  5.087E-10  2.980E-10  1.508E-10             2.558E-09
               0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  7.811E-07  1.699E-06  4.145E-07  5.930E-07  3.487E-06
NW      315.0  1.476E-08  4.452E-08  4.452E-08  3.113E-08  1.777E-08  1.093E-08  7.242E-09  1.700E-09  6.460E-10  1.700E-10
                       0          0          0          0          0          0          0       3452       2285       4607
               1.186E-10  3.580E-10  3.580E-10  2.503E-10  1.428E-10  8.789E-11  5.823E-11  1.367E-11  5.194E-12  1.367E-12             3.580E-10
               0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  4.718E-08  1.187E-08  6.297E-09  6.535E-08
NNW     337.5  3.087E-08  1.198E-07  1.263E-07  1.053E-07  7.109E-08  5.027E-08  3.745E-08  1.357E-08  7.089E-09  3.060E-09
                       0          0          0          0          0          0          0          0        458       1181
               2.482E-10  9.629E-10  1.016E-09  8.465E-10  5.716E-10  4.042E-10  3.011E-10  1.091E-10  5.700E-11  2.460E-11             1.016E-09
               0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  2.610E-08  2.906E-08  5.516E-08
                                                                                                  PREDICTED CANCER CASES --  6.074E-05  2.270E-08
```

TABLE 5. INPUT PARAMETES TO ATMOSPHERIC TRANSPORT MODEL

Methods of estimating the dispersion coefficients: Pasquill-Gifford

This is the recommended method for stack heights of less than 100 meters.

Stack height: 12.2 meters

Stack diameter: 0.69 meters (equivalent diameter)

Stack vent gas temperature: 352°Kelvin

Ejection velocity from stack: 7.54 meters/sec

Stack emission rate: 6.15 x 10^{-3} g/hr

Program options:

- ISCST run in rural mode
- Flat terrain assumed
- Stabilities

  F Maximized concentrations away from plant where most of population is concentrated.

  D Maximized concentrations closer to plant.

APPENDIX C

DRE CALCULATIONS

$$DRE = \frac{W_{(i)in} - W_{(i)out}}{W_{(i)in}} \times 100\%$$

where:

DRE = Destruction and Removal Efficiency
$W_{(i)in}$ = Feed rate of contaminant (i)
$W_{(i)out}$ = Stack emissions of contaminant (i)

TABLE C-1. DESTRUCTION REMOVAL EFFICIENCY (DRE) CALCULATIONS FOR POLYCHLORINATED BIPHENYLS (PCBs)

				Solid and Liquid Feed Parameters					Stack Gas Parameters				
Run No.	Sampling Date	Run Times Start/Stop	Solid(S) or Liquid(L)	Totalizer Reading (lb/hr)	Meter Calib. Factor	Actual Feed Rate (lb/hr)	Percent PCB (%)	PCB Feed Rate (g/min)	Volume Sampled (dscf)	PCBs Detected (ng)	Stack Gas Flowrate (dscfm)	PCB Emiss. Rate (g/min)	Calculated DRE (%)
2	7/29-30/87	21:00/02:42	S	4002.6	1.000	4002.6	1.80	544.9	91.775	63 (a)	2542	0.000002	99.9999996
3	7/30-31/87	23:00/04:13	S	4344.8	1.000	4344.8	1.43	470.1	97.771	63 (a)	2705	0.000002	99.9999995
			L	272.6	1.281	349.2	0.8	21.4					
5	8/1-2/87	23:18/05:13	S	3773.7	1.000	3773.7	1.4	399.8	101.897	575 (b)	2521	0.000014	99.9999965
			L	180.5	(c)	143.5	0.58	6.3					
6	8/31-9/1/87	23:00/24:30	S	1669.5	1.000	1669.5	2.41	304.2	88.577	3058 (d)	2219	0.000077	99.9999879
		1:00/1:15		2226.0	1.000	2226.0	1.60	268.7					
		1:30/1:45		(e)									
		4:30/5:00											
		6:00/6:15											
		7:00/8:15	L	300.0	0.977	293.1	2.8	61.1					

(a) PCBs not detected. Detection limits as follows:
mono-,di-,& tri- isomers -- 2.5 ng
tetra-, penta-, & hexa- isomers -- 5.0 ng
hepta- & octa- isomers -- 7.5 ng
nona- & deca- isomers -- 12.5 ng

(b) PCB detection limits are as noted above,
except the following isoners were detected:
pentachlorobiphenyl -- 120 ng
hexachlorobiphenyl -- 300 ng
heptachlorobiphenyl -- 110 ng

(c) Calibration factor = 0.717(measured flow) + 14.1

(d) PCB detection limits are as noted above,
except the following isoner was detected:
hexachlorobiphenyl -- 3000 ng

(e) For Run No. 6, two seperate batches of solid feed were fed to the system. Three out of every seven drums were from batch 1 and four of every seven drums were from batch 2. Each batch was analyzed seperately.

TABLE C-2. DESTRUCTION REMOVAL EFFICIENCY (DRE) CALCULATIONS FOR CCl_4 (LOW VOST)

			Waste Oil Feed Parameters					Stack Gas Parameters				DRE Calculations	
VOST Run No.	Sampling Date	VOST Run Times Start/Stop (a)	Totalizer Reading (lb/hr)	Meter Calib. Factor	Actual Feed Rate (lb/hr)	Percent CCl4 (%)	CCl4 Feed Rate (g/min)	Volume Sampled (dsL)	CCl4 Detected (ng)	Stack Gas Flowrate (dscfm)	CCl4 Emiss. Rate (g/min)	Calculated DRE (%)	Average DRE (%)
3A	7/30-31/87	23:00/23:42	286.7	1.281	367.2	14.00	389.0	1.476	30	2748	0.0016	99.99960	
3B	7/30-31/87	1:02/1:44	274.7	1.281	351.8	14.00	372.7	2.315	27	2748	0.00091	99.99976	99.99968
3C	7/30-31/87	3:31/4:13	268.0	1.281	343.3	14.00	363.7	1.472	22	2748	0.00116	99.99968	
5A	8/1-2/87	23:18/24:00	162.7	(b)	130.7	27.50	272.0	1.278	54	2546	0.00305	99.99888	
5B	8/1-2/87	1:58/2:41	116.0	(b)	97.3	27.50	202.4	1.266	32	2546	0.00182	99.99910	99.99916
5C	8/1-2/87	4:31/5:13	179.0	(b)	142.4	27.50	296.4	1.303	26	2546	0.00144	99.99951	
6A	8/31-9/1/87	24:33/1:15	278.6	0.977	272.2	14.75	303.8	1.329	85	2030	0.00368	99.99879	99.99912
6B	8/31-9/1/87	1:28/2:10	300.9	0.977	294.0	14.75	328.1	1.331	42	2030	0.00181	99.99945	

(a) VOST run times indicated are the times when the integrated bag samples were collected from the stack. Actual VOST system run times are thus irrelevant for the purposes of determining appropriate waste feed rates.

(b) Calibration factor = 0.717(measured flow) + 14.1

TABLE C-3. DESTRUCTION REMOVAL EFFICIENCY (DRE) CALCULATIONS FOR CCl_4 (HIGH VOST)

			Waste Oil Feed Parameters					Stack Gas Parameters				DRE Calculations	
VOST Run No.	Sampling Date	VOST Run Times Start/Stop	Totalizer Reading (lb/hr)	Meter Calib. Factor	Actual Feed Rate (lb/hr)	Percent CCl4 (%)	CCl4 Feed Rate (g/min)	Volume Sampled (dsL)	CCl4 Detected (ng)	Stack Gas Flowrate (dscfm)	CCl4 Emiss. Rate (g/min)	Calculated DRE (%)	Average DRE (%)
3A	7/30-31/87	23:23/23:43	292.0	1.281	374.1	14.00	396.2	17.463	472	2748	0.0021	99.99947	99.99958
3B	7/30-31/87	24:06/24:26	250.0	1.281	320.3	14.00	339.3	17.142	230	2748	0.0010	99.99969	
3C	7/30-31/87	24:47/1:07	280.0	1.281	358.7	14.00	380.0	17.331	346	2748	0.0016	99.99959	
5A	8/1-2/87	23:19/23:39	164.0	(a)	131.7	27.50	274.0	18.071	626	2546	0.0025	99.99909	99.99869
5B	8/1-2/87	24:22/24:36 24:44/24:50	150.0	(a)	121.7	27.50	253.1	16.149	850	2546	0.0038	99.99850	
5C	8/1-2/87	1:09/1:29	142.4	(a)	116.2	27.50	241.8	17.416	880	2546	0.0036	99.99849	
6A	8/31-9/1/87	23:54/24:14	286.8	0.977	280.2	14.75	312.7	18.041	600	2030	0.0019	99.99939	99.99942
6B	8/31-9/1/87	1:56/2:00 2:08/2:16 2:30/2:38	300.9	0.977	294.0	14.75	328.1	17.881	445	2030	0.0014	99.99956	
6C	8/31-9/1/87	4:58/5:10 6:00/6:08	300.9	0.977	294.0	14.75	328.1	18.341	820	2030	0.0026	99.99922	
6D	8/31-9/1/87	7:24/7:44	300.9	0.977	294.0	14.75	328.1	18.369	499	2030	0.0016	99.99952	

(a) Calibration factor = 0.717(measured flow) + 14.1

TABLE C-4. DESTRUCTION REMOVAL EFFICIENCY (DRE) CALCULATIONS FOR 1,2,4-TRICHLOROBENZENE (TCB)

				Solid and Liquid Feed Parameters					Stack Gas Parameters				
Run No.	Sampling Date	Run Times Start/Stop	Solid(S) or Liquid(L)	Totalizer Reading (lb/hr)	Meter Calib. Factor	Actual Feed Rate (lb/hr)	Percent TCB (%)	TCB Feed Rate (g/min)	Volume Sampled (dscf)	TCB Detected (ng)	Stack Gas Flowrate (dscfm)	TCB Emiss. Rate (g/min)	Calculated DRE (%)
2	7/29-30/87	21:00/02:42	S	4002.6	1.000	4002.6	1.50	454.3	91.775	14000	2542	0.0004	99.99991
3	7/30-31/87	23:00/04:13	S	4344.8	1.000	4344.8	1.60	526.0	97.771	62000	2705	0.0017	99.99968
			L	272.6	1.281	349.2	0.48	12.7					
5	8/1-2/87	23:18/05:13	S	3773.7	1.000	3773.7	1.70	485.4	101.897	9000	2521	0.0002	99.99996
			L	180.5	(a)	143.5	1.0	10.9					
6	8/31-9/1/87	23:00/24:30 1:00/1:15	S	1669.5 2226.0 (b)	1.000 1.000	1669.5 2226.0	1.60 0.60	202.1 101.1	88.577	2280	2219	0.0001	99.99998
		1:30/1:45 4:30/5:00 6:00/6:15 7:00/8:15	L	300.0	0.977	293.1	1.6	35.5					

(a) Calibration factor = 0.717(measured flow) + 14.1

(b) For Run No. 6, two separate batches of solid feed were fed to the system. Three out of every seven drums were from batch 1 and four of every seven drums were from batch 2. Each batch was analyzed separately.

TABLE C-5. DESTRUCTION REMOVAL EFFICIENCY (DRE) CALCULATIONS FOR HEXACHLOROETHANE (HXE)

			Solid Feed Parameters					Stack Gas Parameters				
Run No.	Sampling Date	Run Times Start/Stop	Totalizer Reading (lb/hr)	Meter Calib. Factor	Actual Feed Rate (lb/hr)	Percent HXE (%)	HXE Feed Rate (g/min)	Volume Sampled (dscf)	HXE Detected (ng)	Stack Gas Flowrate (dscfm)	HXE Emiss. Rate (g/min)	Calculated DRE (%)
2	7/29-30/87	21:00/02:42	4002.6	1.000	4002.6	0.88	266.5	91.775	15000	2542	0.000415	99.999844
3	7/30-31/87	23:00/04:13	4344.8	1.000	4344.8	0.93	305.7	97.771	210000	2705	0.005810	99.998100
5	8/1-2/87	23:18/05:13	3773.7	1.000	3773.7	1.10	314.1	101.897	3000	2521	0.000074	99.999976
6	8/31-9/1/87	23:00/24:30	1669.5	1.000	1669.5	1.70	214.8	88.577	500	2219	0.000013	99.999996
		1:00/1:15	2226.0	1.000	2226.0	0.54	91.0					
		1:30/1:45	(a)									
		4:30/5:00										
		6:00/6:15										
		7:00/8:15										

(a) For Run No. 6, two separate batches of solid feed were fed to the system. Three out of every seven drums were from batch 1 and four of every seven drums were from batch 2. Each batch was analyzed separately.

APPENDIX D

DELISTING DATA FROM TRIAL BURN

TABLE D-1. DELISTING ANALYSIS RESULTS ORGANIC DELISTING RESULTS KILN ASH

	Test 2	Test 3	Test 5	Test 5 Dup	Detection Limits	Delisting Criteria
Units	(ug/kg) (ppb)	(ug/kg) (ppb)	(ug/kg) (ppb)	(ug/kg) (ppb)	(ug/kg) (ppb)	(ug/kg) (ppb)
Volatile Organics:						
Carbon Tetrachloride	ND	ND	10	-	10	1000
Chloroform	ND	ND	ND	-	5	NA
Semivolatile/Extractable Organic Compounds:						
1,2,4 Trichlorobenzene	ND	ND	ND	ND	330	NA
Benzo (a) pyrene	ND	ND	ND	ND	330	5000
Benzo (a) anthracene	ND	ND	ND	ND	330	5000
Benzo (b) fluoranthene	ND	ND	ND	ND	330	5000
Chrysene	ND	ND	ND	ND	330	5000
Dibenzo (a,h) anthracene	ND	ND	ND	ND	330	5000
2,5-Dichlorophenol	ND	ND	ND	ND	330	350000
3,4-Dichlorophenol	ND	ND	ND	ND	330	350000
Hexachloroethane	ND	ND	ND	ND	330	1000
Hexachlorophene	ND	ND	ND	ND	170000	200000
Indeno (1,2,3-c,d) pyrene	ND	ND	ND	ND	330	5000
1,2,3,5-Tetrachlorobenzene	ND	ND	ND	ND	330	50000
1,2,4,5-Tetrachlorobenzene	ND	ND	ND	ND	330	50000
2,3,4,5-Tetrachlorophenol	ND	ND	ND	ND	1600	50000
2,3,4,6-Tetrachlorophenol	ND	ND	ND	ND	1600	50000
2,3,4-Trichlorophenol	ND	ND	ND	ND	330	100000
2,4,5-Trichlorophenol	ND	ND	ND	ND	1600	100000
2,4,6-Trichlorophenol	ND	ND	ND	ND	330	1000

TABLE D-2. DELISTING ANALYSIS RESULTS POLYCHLORINATED BIPHENYLS KILN ASH

Units	Test 2 (ug/kg) (ppb)	Test 3 (ug/kg) (ppb)	Test 5 (ug/kg) (ppb)	Detection Limits (ug/kg) (ppb)
Aroclors:				
Aroclor-1016	ND	ND	ND	400
Aroclor-1221	ND	ND	ND	400
Aroclor-1232	ND	ND	ND	400
Aroclor-1242	ND	ND	ND	400
Aroclor-1248	ND	ND	ND	400
Aroclor-1254	ND	ND	ND	400
Aroclor-1260	ND	ND	ND	400
Homologs:				
Monochlorobiphenyl	ND	ND	ND	83
Dichlorobiphenyl	ND	ND	ND	83
Trichlorobiphenyl	ND	ND	ND	83
Tetrachlorobiphenyl	ND	ND	ND	165
Pentachlorobiphenyl	ND	ND	ND	165
Hexachlorobiphenyl	ND	ND	ND	165
Heptachlorobiphenyl	ND	ND	ND	250
Octachlorobiphenyl	ND	ND	ND	250
Nonochlorobiphenyl	ND	ND	ND	400
Decachlorobiphenyl	ND	ND	ND	400

Notes:

Delisting Criteria = total PCB's not to exceed 50,000 ppb

TABLE D-3. DELISTING ANALYSIS RESULTS CHLORINATED DIBENZODIOXINS/FURANS KILN ASH

	Test 2	Test 3	Test 5	Detection Limits
Units	(ug/kg) (ppb)	(ug/kg) (ppb)	(ug/kg) (ppb)	(ug/kg) (ppb)
Homologs:				
Total Tetra-CDD	ND	ND-1	ND-2	0.09
Total Tetra-CDF	ND	ND-1	ND-2	0.09
Total Penta-CDD	ND	ND-1	ND-2	0.09
Total Penta-CDF	ND	ND-1	ND-2	0.09
Total Hexa-CDD	ND	ND-1	ND-2	0.09
Total Hexa-CDF	ND	ND-1	ND-2	0.09
Total Hepta-CDD	ND	ND-1	ND-2	0.09
Total Hepta-CDF	ND	ND-1	ND-2	0.09
Total Octa-CDD	ND	ND-1	ND-2	0.09
Total Octa-CDF	ND	ND-1	ND-2	0.09

Notes:

ND-1 Detection Limit = 0.096 (ng/L)
ND-2 Detection Limit = 0.103 (ng/L)
Delisting criteria = Total not to exceed 1 ppb of 2,3,7,8 tetrachlorodibenzodioxin equivalent

TABLE D-4. DELISTING ANALYSIS RESULTS ORGANIC DELISTING RESULTS CYCLONE ASH

Units	Test 2 (ug/kg) (ppb)	Test 3 (ug/kg) (ppb)	Test 5 (ug/kg) (ppb)	Detection Limits (ug/kg) (ppb)	Delisting Criteria (ug/kg) (ppb)
Volatile Organics:					
Carbon Tetrachloride	ND	ND	6 J	10	1000
Chloroform	ND	ND	ND	5	NA
Semivolatile/Extractable Organic Compounds:					
1,2,4 Trichlorobenzene	ND	ND	ND	330	NA
Benzo (a) pyrene	ND	ND	ND	330	5000
Benzo (a) anthracene	ND	ND	ND	330	5000
Benzo (b) fluoranthene	ND	ND	ND	330	5000
Chrysene	ND	ND	ND	330	5000
Dibenzo (a,h) anthracene	ND	ND	ND	330	5000
2,5-Dichlorophenol	ND	ND	ND	330	350000
3,4-Dichlorophenol	ND	ND	ND	330	350000
Hexachloroethane	ND	ND	ND	330	1000
Hexachlorophene	ND	ND	ND	170000	200000
Indeno (1,2,3-c,d) pyrene	ND	ND	ND	330	5000
1,2,3,5-Tetrachlorobenzene	ND	ND	ND	330	50000
1,2,4,5-Tetrachlorobenzene	ND	ND	ND	330	50000
2,3,4,5-Tetrachlorophenol	ND	ND	ND	1600	50000
2,3,4,6-Tetrachlorophenol	ND	ND	ND	1600	50000
2,3,4-Trichlorophenol	ND	ND	ND	330	100000
2,4,5-Trichlorophenol	ND	ND	ND	1600	100000
2,4,6-Trichlorophenol	ND	ND	ND	330	1000

NOTES:

6 J = 6 ppb detection by linear extrapolation of calibration curve

TABLE D-5. DELISTING ANALYSIS RESULTS POLYCHLORINATED BIPHENYLS CYCLONE ASH

Units	Test 2 (ug/kg) (ppb)	Test 3 (ug/kg) (ppb)	Test 5 (ug/kg) (ppb)	Detection Limits (ug/kg) (ppb)
Aroclors:				
Aroclor-1016	ND	ND	ND	400
Aroclor-1221	ND	ND	ND	400
Aroclor-1232	ND	ND	ND	400
Aroclor-1242	ND	ND	ND	400
Aroclor-1248	ND	ND	ND	400
Aroclor-1254	ND	ND	ND	400
Aroclor-1260	ND	ND	ND	400
Homologs:				
Monochlorobiphenyl	ND	ND	ND	83
Dichlorobiphenyl	ND	ND	ND	83
Trichlorobiphenyl	ND	ND	ND	83
Tetrachlorobiphenyl	ND	ND	ND	165
Pentachlorobiphenyl	ND	ND	ND	165
Hexachlorobiphenyl	ND	ND	ND	165
Heptachlorobiphenyl	ND	ND	ND	250
Octachlorobiphenyl	ND	ND	ND	250
Nonochlorobiphenyl	ND	ND	ND	400
Decachlorobiphenyl	ND	ND	ND	400

Notes:

Delisting Criteria = total PCB's not to exceed 50,000 ppb

TABLE D-6. DELISTING ANALYSIS RESULTS CHLORINATED DIBENZODIOXINS/FURANS CYCLONE ASH

Units	Test 2 (ug/kg) (ppb)	Test 3 (ug/kg) (ppb)	Test 5 (ug/kg) (ppb)	Detection Limits (ug/kg) (ppb)
Homologs:				
Total Tetra-CDD	ND	ND-1	ND-2	0.092
Total Tetra-CDF	ND	ND-1	ND-2	0.092
Total Penta-CDD	ND	ND-1	1.9	0.092
Total Penta-CDF	ND	ND-1	ND-2	0.092
Total Hexa-CDD	ND	ND-1	ND-2	0.092
Total Hexa-CDF	ND	ND-1	ND-2	0.092
Total Hepta-CDD	ND	ND-1	ND-2	0.092
Total Hepta-CDF	ND	ND-1	0.7	0.092
Total Octa-CDD	ND	ND-1	0.3	0.092
Total Octa-CDF	ND	ND-1	ND-2	0.092

Notes:

ND-1 Detection Limit = 0.097 (ng/L)

ND-2 Detection Limit = 0.096 (ng/L)

Delisting criteria = Total not to exceed 1 ppb of 2,3,7,8 tetrachlorodibenzodioxin equivalent

Equivalent 2,3,7,8-TCDD for Test 5 cyclone ash is 0.19 ppb which meets delisting criteria

TABLE D-7. DELISTING ANALYSIS RESULTS ORGANIC DELISTING RESULTS SCRUBBER PURGE WATER

Units	Test 2 Prior (ug/L) (ppb)	Test 2 (ug/L) (ppb)	Test 3 Prior (ug/L) (ppb)	Test 3 (ug/L) (ppb)	Test 5 (ug/L) (ppb)	Test 5 Dup (ug/L) (ppb)	Test 5 Prior (ug/L) (ppb)	Detection Limits (ug/L) (ppb)	Delisting Criteria (ug/kg) (ppb)
Volatile Organics:									
Carbon Tetrachloride	ND	ND		ND	ND	-		10	5
Chloroform	ND	ND		ND	ND	-		5	NA
Semivolatile/Extractable Organic Compounds:									
1,2,4 Trichlorobenzene	ND	ND	ND	ND	ND	ND	ND	10	NA
Benzo (a) pyrene	-	ND	-	ND	ND	ND-1	-	10	10
Benzo (a) anthracene	-	ND	-	ND	ND	ND-1	-	10	10
Benzo (b) fluoranthene	-	ND	-	ND	ND	ND-1	-	10	10
Chrysene	-	ND	-	ND	ND	ND-1	-	10	10
Dibenzo (a,h) anthracene	-	ND	-	ND	ND	ND-1	-	10	10
2,5-Dichlorophenol	-	ND	-	ND	ND	ND-1	-	10	15
3,4-Dichlorophenol	-	ND	-	ND	ND	ND-1	-	10	15
Hexachloroethane	ND	ND	ND	ND	ND	ND-1	ND	10	25
Hexachlorophene	-	ND	-	ND	ND	ND-1	-	5000	10000
Indeno (1,2,3-c,d) pyrene	-	ND	-	ND	ND	ND-1	-	10	10
1,2,3,5-Tetrachlorobenzene	-	ND	-	ND	ND	ND-1	-	10	10000
1,2,4,5-Tetrachlorobenzene	-	ND	-	ND	ND	ND-1	-	10	10000
2,3,4,5-Tetrachlorophenol	-	ND	-	ND	ND	ND-1	-	50	5000
2,3,4,6-Tetrachlorophenol	-	ND	-	ND	ND	ND-1	-	50	5000
2,3,4-Trichlorophenol	-	ND	-	ND	ND	ND-1	-	10	10000
2,4,5-Trichlorophenol	-	ND	-	ND	ND	ND-1	-	50	10000
2,4,6-Trichlorophenol	-	ND	-	ND	ND	ND-1	-	10	100

Notes:

ND-1 Detection Limits are double the listed ones due to limited sample volume.

TABLE D-8. DELISTING ANALYSIS RESULTS POLYCHLORINATED BIPHENYLS SCRUBBER PURGE WATER

Units	Test 2 Prior (ug/L) (ppb)	Test 2 (ug/L) (ppb)	Test 3 Prior (ug/L) (ppb)	Test 3 (ug/L) (ppb)	Test 5 Prior (ug/L) (ppb)	Test 5 (ug/L) (ppb)	Detection Limits (ug/L) (ppb)
Aroclors:							
Aroclor-1016	-	ND	-	ND	-	ND-1	0.5
Aroclor-1221	-	ND	-	ND	-	ND-1	0.5
Aroclor-1232	-	ND	-	ND	-	ND-1	0.5
Aroclor-1242	-	ND	-	ND	-	ND-1	0.5
Aroclor-1248	-	ND	-	ND	-	ND-1	0.5
Aroclor-1254	-	ND	-	ND	-	ND-1	0.5
Aroclor-1260	-	ND	-	ND	-	41	0.5
Homologs:							
Monochlorobiphenyl	ND	ND	ND	ND	ND	ND	2.5
Dichlorobiphenyl	ND	ND	ND	ND	ND	ND	2.5
Trichlorobiphenyl	ND	ND	ND	ND	ND	ND	2.5
Tetrachlorobiphenyl	ND	ND	ND	ND	ND	ND	5
Pentachlorobiphenyl	ND	ND	ND	ND	ND	ND	5
Hexachlorobiphenyl	ND	ND	4600	ND	ND	ND	5
Heptachlorobiphenyl	ND	ND	3800	ND	ND	ND	7.5
Octachlorobiphenyl	ND	ND	ND	ND	ND	ND	7.5
Nonochlorobiphenyl	ND	ND	ND	ND	ND	ND	12.5
Decachlorobiphenyl	ND	ND	ND	ND	ND	ND	12.5

Notes:

ND-1 Detection Limits = 4.0

Delisting Criteria = PCB's not to exceed 1000 ppb

TABLE D-9. DELISTING ANALYSIS RESULTS CHLORINATED DIBENZODIOXINS/FURANS SCRUBBER PURGE WATER

Units	Test 2 Prior (ng/L) (ppt)	Test 2 (ng/L) (ppt)	Test 2 Dup (ng/L) (ppt)	Test 3 Prior (ng/L) (ppt)	Test 3 (ng/L) (ppt)	Test 5 Prior (ng/L) (ppt)	Test 5 (ng/L) (ppt)	Test 5 Dup (ng/L) (ppt)	Detection Limits (ng/L) (ppt)
Homologs:									
Total Tetra-CDD	ND	ND	ND	ND	ND	ND-2	ND-1	ND	10
Total Tetra-CDF	ND	ND	ND	ND	ND	260	180	270	10
2,3,7,8 Tetra-CDF	-	-	-	-	-	-	90	90	10
Total Penta-CDD	ND	ND	ND	ND	ND	ND-2	ND-1	ND	10
Total Penta-CDF	ND	ND	ND	ND	ND	120	350	310	10
Total Hexa-CDD	ND	ND	ND	ND	ND	ND-2	ND-1	ND	10
Total Hexa-CDF	ND	ND	ND	ND	ND	50	140	100	10
Total Hepta-CDD	ND	ND	ND	ND	ND	ND-2	ND-1	ND	10
Total Hepta-CDF	ND	ND	ND	ND	ND	17	17	20	10
Total Octa-CDD	ND	ND	<13	ND	<13	ND-2	ND-1	ND	10
Total Octa-CDF	ND	ND	ND	ND	ND	ND-2	2.4	ND	10

Notes:

ND-1 Detection Limits = 10.5

ND-2 Detection Limits = 10.2

Delisting criteria = Total not to exceed 10 ppt of 2,3,7,8 tetrachlorodibenzodioxin equivalent

TABLE D-10. DELISTING ANALYSIS RESULTS ORGANIC DELISTING RESULTS SEPARATOR SLUDGE

	Test 2	Test 3	Test 5	Detection Limits	Delisting Criteria
Units	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)
Volatile Organics:					
Carbon Tetrachloride	ND	ND	ND	10	1000
Chloroform	ND	ND	ND	5	NA
Semivolatile/Extractable Organic Compounds:					
1,2,4 Trichlorobenzene	ND	ND-1	ND-2	20	NA
Benzo (a) pyrene	ND	ND	ND	10	5000
Benzo (a) anthracene	ND	ND	ND	10	5000
Benzo (b) fluoranthene	ND	ND	ND	10	5000
Chrysene	ND	ND	ND	10	5000
Dibenzo (a,h) anthracene	ND	ND	ND	10	5000
2,5-Dichlorophenol	ND	ND	ND	10	350000
3,4-Dichlorophenol	ND	ND	ND	10	350000
Hexachloroethane	ND	ND	ND	10	1000
Hexachlorophene	ND	ND	ND	5000	200000
Indeno (1,2,3-c,d) pyrene	ND	ND	ND	10	5000
1,2,3,5-Tetrachlorobenzene	ND	ND	ND	10	50000
1,2,4,5-Tetrachlorobenzene	ND	ND	ND	10	50000
2,3,4,5-Tetrachlorophenol	ND	ND	ND	50	50000
2,3,4,6-Tetrachlorophenol	ND	ND	ND	50	50000
2,3,4-Trichlorophenol	ND	ND	ND	10	100000
2,4,5-Trichlorophenol	ND	ND	ND	50	100000
2,4,6-Trichlorophenol	ND	ND	ND	10	1000

Notes:

ND-1 Detection Limit = 30 (ug/L)
ND-2 Dection Limit = 500 (ug/L)

TABLE D-11. DELISTING ANALYSIS RESULTS POLYCHLORINATED BIPHENYLS SEPARATOR SLUDGE

Units	Test 2 (ug/L) (ppb)	Test 3 (ug/L) (ppb)	Test 5 (ug/L) (ppb)	Detection Limits (ug/L) (ppb)
Aroclors:				
Aroclor-1016	ND	ND	ND-9	1.5
Aroclor-1221	ND	ND	ND-9	1.5
Aroclor-1232	ND	ND	ND-9	1.5
Aroclor-1242	ND	ND	ND-9	1.5
Aroclor-1248	ND	ND	ND-9	1.5
Aroclor-1254	ND	ND	ND-9	1.5
Aroclor-1260	ND	ND	63.3	1.5
Homologs:				
Monochlorobiphenyl	ND	ND-1	ND-5	5.5
Dichlorobiphenyl	ND	ND-1	ND-5	5.5
Trichlorobiphenyl	ND	ND-1	ND-5	5.5
Tetrachlorobiphenyl	ND	ND-2	ND-6	11
Pentachlorobiphenyl	ND	ND-2	ND-6	11
Hexachlorobiphenyl	ND	ND-2	ND-6	11
Heptachlorobiphenyl	ND	ND-3	ND-7	17
Octachlorobiphenyl	ND	ND-3	ND-7	17
Nonochlorobiphenyl	ND	ND-4	ND-8	28
Decachlorobiphenyl	ND	ND-4	ND-8	28

Notes:

ND-1 Detection Limit = 7.6 (ug/L)
ND-2 Detection Limit = 15 (ug/L)
ND-3 Detection Limit = 23 (ug/L)
ND-4 Detection Limit = 38 (ug/L)
ND-5 Detection Limit = 4.0 (ug/L)
ND-6 Detection Limit = 7.5 (ug/L)
ND-7 Detection Limit = 11.0 (ug/L)
ND-8 Detection Limit = 19.0 (ug/L)
ND-9 Detection Limit = 3.8 (ug/L)
Delisting Criteria = total PCB's not to exceed 50,000 ppb

TABLE D-12. DELISTING ANALYSIS RESULTS CHLORINATED DIBENZODIOXINS/FURANS SEPARATOR SLUDGE

	Test 2	Test 3	Test 5	Detection Limits
Units	(ng/L) (ppt)	(ng/L) (ppt)	(ng/L) (ppt)	(ng/L) (ppt)
Homologs:				
Total Tetra-CDD	ND	ND-1	ND-1	40
Total Tetra-CDF	4.3	ND	82000*	22.2
2,3,7,8 Tetra-CDF	ND	-	ND	10
Total Penta-CDD	ND	ND-1	ND-1	40
Total Penta-CDF	8.5	ND	150000*	22.2
Total Hexa-CDD	ND	4.7	250	40
Total Hexa-CDF	ND	ND-1	103000*	40
Total Hepta-CDD	ND	ND-1	103	40
Total Hepta-CDF	ND	ND-1	52000*	40
Total Octa-CDD	16	13.2	ND	22.2
Total Octa-CDF	ND	ND-1	ND-1	40

Notes:

* Estimated value-beyond linear range

ND-1 Detection Limit = 22.2 (ng/L)

TABLE D-13. DELISTING ANALYSIS RESULTS EP TOXICITY RESULTS SCRUBBER PURGE WATER AND SEPARATOR SLUDGE

	Kiln Ash				Cyclone				
Metal	Test 2	Test 2 Dup	Test 3	Test 5	Test 2	Test 3	Test 5	Detection Limits	Delisting Criteria
Units	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)
Arsenic	305	ND	85	305	175	375	100	70	50000
Barium	420	32	320	570	550	750	240	-	100000
Cadmium	ND	ND	ND	ND	ND	ND	ND	9	1000
Chromium	34	235	35	30	23	35	27	-	5000
Lead	60	ND	ND	ND	ND	ND	42	40	5000
Mercury	ND	ND	ND	ND	ND	ND	1.4	0.2	200
Nickel	24	511	40	27	18	16	16	-	NA
Selenium	45	ND	ND	ND	ND	50	ND	30	1000
Silver	6	6.7	ND	8	ND	7	6	3	3000

TABLE D-14. DELISTING ANALYSIS RESULTS EP TOXICITY RESULTS KILN ASH AND CYCLONE ASH

	Scrubber Purge Water								Separator Sludge					
Metal	Test 2 Prior	Test 2	Test 2 Dup	Test 3 Prior	Test 3	Test 3 Dup	Test 5	Test 5 Dup	Test 2	Test 3	Test 3 Dup	Test 5	Detection Limits	Delisting Criteria
Units	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)	(ug/L) (ppb)
Arsenic	102	ND	ND	107	ND-1	ND-1	ND	ND	350	449	492	628	5	50000
Barium	62	32	32	71	42	36	42	43	16	13	14	8	-	100000
Cadmium	9	ND	ND	ND	ND	ND	ND	ND	ND	20	12	10	9	1000
Chromium	150	228	235	220	305	235	290	301	46	244	292	126	-	5000
Lead	140	ND	ND	150	51	71	143	112	76	152	186	158	5	5000
Mercury	ND	ND	ND	ND	0.52	2.7	2.2	4.9	ND	ND	NA?	2.1	0.2	200
Nickel	205	492	511	381	632	481	567	582	64	474	576	240	-	NA
Selenium	175	ND	ND	130	ND-1	ND-1	40.7	0	243	304	334	298	5	1000
Silver	23	4.7	6.7	20	ND	ND	ND	ND	13	23	32	16	5	3000

Notes:

ND-1 Detection Limit = 20 (ug/L) Sample needed dilution due to sodium interference.